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WARM-BLAST

STEAM-BOILER FURNACE.

as boiler tests are usually conducted, are of very limited value. Too many unfounded assumptions are usually made. "Coal" is taken as equal to something to be found in tables, sometimes even without allowing for surface moisture, which may be dried out; yet there is more difference in coal than there is in boilers, rejecting boilers notoriously defective, and surface water will range all the way from 0.5 per cent. to 8 per cent. "Steam" is taken as of fixed and standard quality, as if it were dry, saturated steam, which is possible only when no steam is drawn from the boiler, and when none has been drawn from it for some little time.

The hygrometric condition of the air is neglected, and its temperature and its barometric pressure; or, if observations are taken of the hygrometer, thermometer and barometer, the corrections these instruments would supply are rarely made. Steam-gauge pressures indicate different absolute pressures, and different quantities of heat, at varying barometric pressures.

Little attention is usually given to the question: How large a proportion of the air in the chimney gases really passes through the incandescent fuel on the grates? and how much infiltrates at cracked or ill-fitting doors, at cracks in the brick-work, and between the brick-work and arch front, or through the brick-work itself? Lastly, it is believed that this is the first serious attempt, outside of the technical school or laboratory, to carry out a thorough, continuous analysis of flue gases—by far the most important point of attack upon the difficult problem of coal combustion. Unless the composition of the escaping gases is known, nothing is known; this accurately ascertained, and their weight and temperature, almost everything which it is desirable to know is ascertainable.

Some of the instruments devised and constructed for these experiments, and used in carrying them on, will be found of interest. Such are the calorimeter, the water-platinum pyrometer, the two-fluid anemometer and the incased aneroid barometer.

This warm-blast apparatus seems to afford a means of securing a net saving of 10 to 18 per cent. over the best attainable practice with natural chimney draft and with air supplied to the furnace at usual external air temperatures; at least five times as much as can be saved by any and all other methods, save the Green Economizer, which is an analogous device, only available where large quantities of warm water are in constant demand; and should commend itself to the attention of all large consumers of coal, as soon as the durability of the apparatus is well established by sufficiently

protracted use. There are some incidental advantages, growing out of the more complete control of the rate of combustion; and there is, it must be said, an offset to these advantages in the more rapid deterioration of fire grates, the importance of which can only be determined by prolonged experience.

The expense of these experiments, which grew out of a suggestion at the end of a pamphlet "On the Combustion of Fuel" * was borne by an association of mill owners and manufacturers. Their object may be stated as follows:

1. To ascertain how large a portion of the heat generated by the combustion of commercial coals, with the best attainable practice by natural chimney draft, escapes through the chimney, serving no useful purpose except in producing the draft.

2. To ascertain what portion of such escaping heat could practically be arrested and returned to the furnace in a warm blast, by means of an apparatus of admissible size and cost.

3. To determine the form and dimensions of apparatus sufficiently well adapted to this purpose.

4. To ascertain the cost of driving a blower to supplement the loss of chimney draft suffered in consequence of the reduced temperature of the finally-escaping flue gases.

5. To obtain by observation the data for striking a balance of advantages and disadvantages resulting from the use of such apparatus, as compared with natural draft, under conditions substantially similar; and

6. To obtain as much information as such experiments could be made to yield upon all questions relating to the economical combustion of coals and the generation of steam.

It will be apparent, on reflection, that the problem was far from simple, and by no means easy. It would not do to confine the experiments to a boiler with the warm-blast apparatus, and then to institute a comparison with alleged results obtained in ordinary practice, since there might easily be found in "ordinary practice" defects of care, skill or arrangement, which would make the comparison unduly favorable to the device. Again, the use of a blower, or exhaust-fan, by giving control of the draft, would give facility for more rapid combustion, and, consequently, for more rapid steam generation, which, unless guarded against or duly allowed for, might, by increased "priming"—water entrained with the steam but unevaporated—have given a deceptive appearance of ad-

* See Appendices III. and IV.

vantage arising from a positive loss; a favorite ruse of empirical boiler-improvers time out of mind.

It was therefore thought necessary to lay out a comprehensive series of experiments; *first*, with a boiler similar in form, dimensions and setting to all the fifty boilers of the Pacific Mills, in order to ascertain just how near to theoretically perfect conditions we could bring that boiler, in actual practice, week by week; and *secondly*, just what proportion of the inevitable loss of heat was suffered at the chimney, and what degree of efficiency was attainable.

This knowledge gained, as a secure basis of comparison, similar experiments, modified only so far as necessary to adapt them to the modified arrangement of the boiler setting, were carried out with the boiler fitted with the warm-blast apparatus: the two sets of experiments being designated, for distinction, "cold blast" (or Pacific) and "warm blast."

The observations covered the following points:

1. Coal.—Time of each firing and quantity fired; quality and condition; temperature; samples taken at every firing, and analysis of the daily samples.

2. Refuse.—Divided into "cinders," picked out by hand, yielding by analysis about 41 per cent. of carbon; partly burned coal, about 62 per cent. carbon; and ashes, of several grades, about 14 per cent. carbon. Several screens of different degrees of fineness were used, and the several grades were weighed, sampled and analyzed, for the few first weeks. But a very perfect check upon this work (which will be pointed out farther on), enabled us to dispense with these laborious and costly analyses of refuse.

3. Water.—Quantity fed into the boiler; time and weight noted every time a tank was emptied; height of water level in glass water-gauge attached to boiler—temperature and height noted every quarter of an hour.

4. Air.—Quantity, with cold-blast, deduced from the composition of the flue gases, determined by continuous analysis, together with the tension of these gases, and their temperature: the tension ascertained by means of a large aneroid barometer inclosed in an air-tight case, communicating through a tube with the flue, and, by a three-way cock, with the atmosphere; and the temperature by means of mercurial (chemical) thermometers, inserted in tubes filled with sperm oil, set in the flue. With the warm blast, in addition to the foregoing, a record was kept of the revolutions of a Root blower

of known measured capacity, and ascertained rate of leakage. The hygrometric state of the air was deduced by quarter-hourly notes of a hygrometer. The temperature of the external air and of the air of the boiler-room was regularly noted, and with the warm blast, the temperature on entering the "abstractor," to be warmed by the outflowing gases, and again on emerging from the abstractor, to enter the ash-pit.

There was also a hot-air flue for highly heating (at will) a part of the air, with provision for introducing it at a "split bridge," with dampers to regulate its admission, and provision for observing the temperature of such highly heated air.

5. Gaseous Products of Combustion.—Continuous analysis by the gravimetric method, each forenoon's and each afternoon's production by itself, with occasional special examinations of shorter periods, to observe the effect of modes of firing, of introducing hot air, and other variations from the usual conditions. The gases given off during the night from banked fires were also continuously analyzed and their volume determined, in the experiments with cold blast; but with the warm blast, the dampers were finally made so tight that no current could be detected, and the loss—whatever it was—could not be estimated. This gravimetric method of gas analysis, which is very interesting and not hitherto generally practiced, will be fully described in its proper place.

6. Steam.—Pressure recorded by an Edson pressure-recording gauge, and noted every quarter of an hour by a test gauge, known to agree with a mercurial column; supplemented by quarter-hourly readings of a signal service (mercurial) barometer; and its quality as to saturation, moisture or superheating ascertained. This was done with cold blast, in which case the boiler had no superheating surface, by a steam calorimeter, to be hereafter described; and with warm blast, in which case there was ample superheating surface and constant superheating in fact, by the thermometer.

7. Fire.—Temperature in center of incandescent coal, at bridge wall, and at the pier, where the gases are about to enter the boiler flues, taken by the water-platinum pyrometer.

8. Flue Gases.—Their temperature on emerging from the boiler flues, in smoke-box; on entering the abstractor; on emerging from the abstractor, and on passing to the exhaust blower.

9. Brick-work.—Radiation from its surface; conduction of heat from inside to outside.

For carrying out these experiments, several new instruments, or

new forms of old ones, were devised and constructed. The more important of these will be found described in the proper place.

It is obvious that these observations and experiments could not all be carried on simultaneously and kept up throughout the whole period covered by the tests, without a larger force of assistants than it would have been judicious to employ. Nor was this necessary. Calorimetric experiments on the quality of steam, for instance, which are delicate and laborious, demanding the closest attention of skillful observers, can be so timed with respect to the rate of steam generation and consumption as fairly to represent ordinary conditions. Such experiments were, in fact, confined to one week, July 11–16, 1881, when fourteen experiments, fully detailed in the appropriate place, were made and recorded.

Pyrometric experiments in the fire, at the bridge wall and at the pier, were chiefly directed to ascertaining the temperature of new fires, well-kindled fires, new, old, or spent fires, and banked fires, with anthracite and with bituminous coal.

Experiments on the radiation and conduction of brick-work were made as time and convenience would permit.

Valuable information was obtained on the necessity of carefully sampling the gaseous products of combustion, which exist in flues and chimneys in most heterogeneous mixtures, far from being equally diffused; and on practicable methods of satisfactory sampling, all of which are fully described.

The power consumed in driving the suction blower was carefully ascertained. Some curious experiments, not devoid of interest, were made to ascertain the quantity of solid carbon carried off in black smoke with the chimney gases from bituminous coal—a very small proportion of the carbon consumed.

Each one of the tests of evaporation here reported was carried on continuously during an entire week. Early on Monday morning, the boiler and the water it contained being cooled down nearly to the temperature of the boiler room, a wood fire was lighted and kept up until the steam gauge showed about 50 pounds pressure per square inch, whereupon the fire was drawn, and the furnace and ash-pit were cleaned out. A quantity of wood, usually about 260 pounds, weighed and sampled for analysis,* was then put on the fire grate for kindling, and coal was thrown on at the discretion

* Several analyses of the wood were made, but as these analyses are troublesome, as the quantity of wood used was small, and as dry wood is nearly uniform in composition, the usual ratio, 40 per cent. of coal, was adopted.

of the skillful and attentive fireman, and weighed at every firing. A platform scale, fitted with a box of plank, having sides and a back, but open in front, was kept exclusively for weighing coal. 500 pounds of coal filled the box conveniently full—the box itself being balanced by a counterpoise on the scale beam. The weight of a charge and the time of charging being noted, the weight was again taken and noted after each firing, and the time of opening and closing the fire door was also noted. The successive differences were the quantities thrown on the grate at the respective firings, and their sums were the total quantities fired during the period covered by the notes summed up.

The notes of each day's firing were plotted, graphically, on section paper, to guard against errors and omissions.

Near the close of the day, as early as the demand for steam would permit, the fire was "banked," all dampers were closed and so left till morning, when the dampers were opened, the fire was cleaned, and fresh coal was thrown on. It is, therefore, evident that all the fuel consumed during the week has been charged to the boiler, except the wood consumed on each Monday morning in raising steam to about fifty pounds pressure.

The actual pressure at starting the fire and at opening the dampers in the morning, was observed and recorded, together with the height of water in the boiler, this latter being taken from a scale attached to the glass water-gauge; and similar observations were noted at stopping, as well as every fifteen minutes of the day—and sometimes of the night—and the differences in height of water and in pressure of steam, between starting on Monday morning and stopping at noon on Saturday, were duly allowed for. A table will be found on a subsequent page giving the number of pounds of water contained in the boiler at each inch in height of the glass water-gauge, from 0 to 10 inches, and for pressures varying by 5 pounds, from atmospheric pressure to 80 pounds above, with differences for convenience of interpolation.

As to the omission of the quantity of wood consumed in raising steam on Monday morning, it is proper to forestall criticism by the remark that in no other way could the several trials be made so strictly comparable as by starting and stopping in each case, as nearly as possible, with steam at the same pressure and with water at the same level. The same method was pursued in every case, so that the comparison of one case with another is as just as it seems possible to make it without continuous uninterrupted firing.

The anthracite coal was Lackawanna, taken from "pockets" in Boston, egg size, very uniform, and of good quality and reasonably dry, the analysis showing only 2.78 per cent. of water.

The bituminous coal was Cumberland, kept under cover, and was also of good quality, and contained even less water than the anthracite.

Samples about as large as a coffee-bean were taken at each firing —averaging about one from every tenth lump (of the anthracite), each full day's samples filling a compartment three inches cube, in a box containing six such compartments; and all the samples of each week were pulverized and treated in the usual manner.

Two independent analyses were made of each week's samples, and sometimes, when there appeared to be too much difference, a third analysis was made for confirmation or correction. A considerable quantity of each of the pulverized samples, each separately bottled and labeled, is preserved for future verification, if desired.

A summary of the results of coal analysis is subjoined (Table I.), the anthracite used with cold blast being the mean of five weeks' firing.

TABLE I.

CONSTITUENTS OF COAL.	BOILER WITH COLD BLAST.		BOILER WITH WARM BLAST.	
	Anthracite.	Bituminous.	Anthracite.	Bituminous.
Carbon	82.43	81.03	81.51	81.71
Hydrogen	1.86	3.84	1.89	3.79
Ash	10.12	7.19	11.83	5.75
Water	2.78	.63	2.49	1.02
Oxygen		4.49		4.91
Nitrogen		2.00		2.00
Sulphur	2.81*	.82	2.28*	.82
	100.00	100.00	100.00	100.00

The two boilers with which experiments were made were precisely alike, and were substantially like all the boilers in use at the Pacific Mills, about fifty in number, some of which are a little less in length. They are of the class known as externally fired, return tubular boilers. The cylindrical shell, of flange iron 0.375 inches thick, is 60 inches in diameter outside of the small courses, double-riveted in the longitudinal seams, and 21 feet in extreme length,

* The Oxygen, Nitrogen and Sulphur not separated in the anthracite.

including the smoke-box cover; the smoke-box at the front end being 1 foot long, and the flues 20 feet. These are 3.5 inches in diameter outside, lap-welded iron tubes, set in squares and in straight rows both horizontally and vertically, 4.5 inches between centers, and therefore with 1 inch clear space between them.

They are arranged in 7 horizontal rows; 4 rows of 11 tubes each, one of 9, one of 7, and one of 5, making 65 tubes in all. The middle tube of the row next to the upper row, is in the center of the shell, which leaves at the bottom a space of 5.37 inches between the lower side of the flues and the inner side of the small courses, 4.87 inches between the flues and the rivet-heads, and at the nearest, 3.09 inches, radially, between the flues and the smaller courses, and 2.59 inches between the nearest tubes and the rivet-heads. The provision for water circulation is therefore sufficient, and is further aided by setting the smoke-box entirely forward of the arch front, so that a length of 12 inches of the water space at the front end, immediately back of the smoke-box, is embraced in the brick-work, and shielded from the direct action of the fire, which, it is believed, produces a downward current at that point, to supply the rapid evaporation directly over the fire-grates. These are 5 feet 2 inches long from the fire-brick lining of the arch front to the bridge wall.

The fire-grates of the original "Pacific" boiler, with which the cold-blast experiments were made, were 5 feet wide between the side walls; those of the new boiler, with hot-blast apparatus, 5 feet 4 inches wide. The side walls of the Pacific boiler are offset above the grates, until at the level of the bridge wall, they are 5 feet 6 inches apart, at which point they are 24 inches thick; and are closed over against the boiler at the middle of its height, where the space is 3 inches to the smaller courses, 2.62 inches to the larger courses, and 2.12 inches to the rivet-heads. The brick-work closing the space between the side walls and the boiler, is 9 inches in depth, and above it the right-hand side wall is carried up 3 inches above the top of the boiler, where the covering bars are laid on. The left-hand side is occupied by a horizontal brick flue, conveying the gases of combustion, received from the smoke-box through a plate-iron smoke bonnet, to the rear of the boiler setting, where a vertical brick flue, 16 × 36 inches, conducts them down below the floor of the boiler-house, to enter the side of an underground brick flue extending along in the rear of the boilers to the chimney, located just outside of the boiler-house, as seen in Fig. 1.

The covering over the boiler is as follows: suitable cast-iron bars of ⊥ section are laid about 3 feet apart, across the boiler, supported by the side wall of the boiler setting on one side, and by the wall of the flue on the other side. On the flanges of these bars were placed, at intervals of a brick's length—8 inches—smaller bars, of similar section, on the flanges of which bricks were placed; and on the covering so made two courses of brick were laid in mortar. The space between this covering and the boiler is left vacant. Suitable openings are left for access to the man-hole cover, safety-valve seat, and feed-water inlet. The side and end walls, reduced to 12 inches in thickness, are carried up two or three courses higher than the covering over the boiler, in the form of a low parapet.

The boiler is supported at the front end by the arch front, at the rear end by a massive pier of fire-brick, and on the side wall by strong lugs, two on each side, riveted to the boiler.

Feed water is supplied to the boiler at the top, near the rear end, through a nozzle provided for the purpose, through a pipe carried down to and into the water, and around the flues nearly to the bottom, to enable the feed water to acquire nearly the temperature of the water in the boiler before its discharge from the pipe.

All the experiments with cold blast, and with natural chimney draft, were made with this Pacific boiler and boiler setting, as above described. Subsequently, the warm-blast apparatus was placed on top of this boiler; but without any alteration of the boiler-setting, except to discontinue the use of the horizontal flue on top and the vertical flue in the rear; and to make flues on each side for the warm blast, from the front end of the abstractors to the ash-pit. It will be seen from this description that this boiler has no superheating surface, unless the two or three square feet above the water level in the smoke-box be so considered, and as the gases here are but a few degrees warmer than the steam in the boiler, this is too trivial to produce a sensible effect.

The top of the fire-grates is 20 inches below the bottom of the boiler; the top of the bridge wall, 12 inches above the grates, and the pavement back of the bridge wall, 22 inches below the top of the bridge wall, and 30 inches below the boiler. The whole—furnace and combustion chamber—is lined with fire-brick, all headers in the furnace; and the rear wall is brought over by offsets, nearly to contact with the end of the boiler, above the flues, large tile, 18 inches long, 12 inches wide, and 3 inches thick, being freely

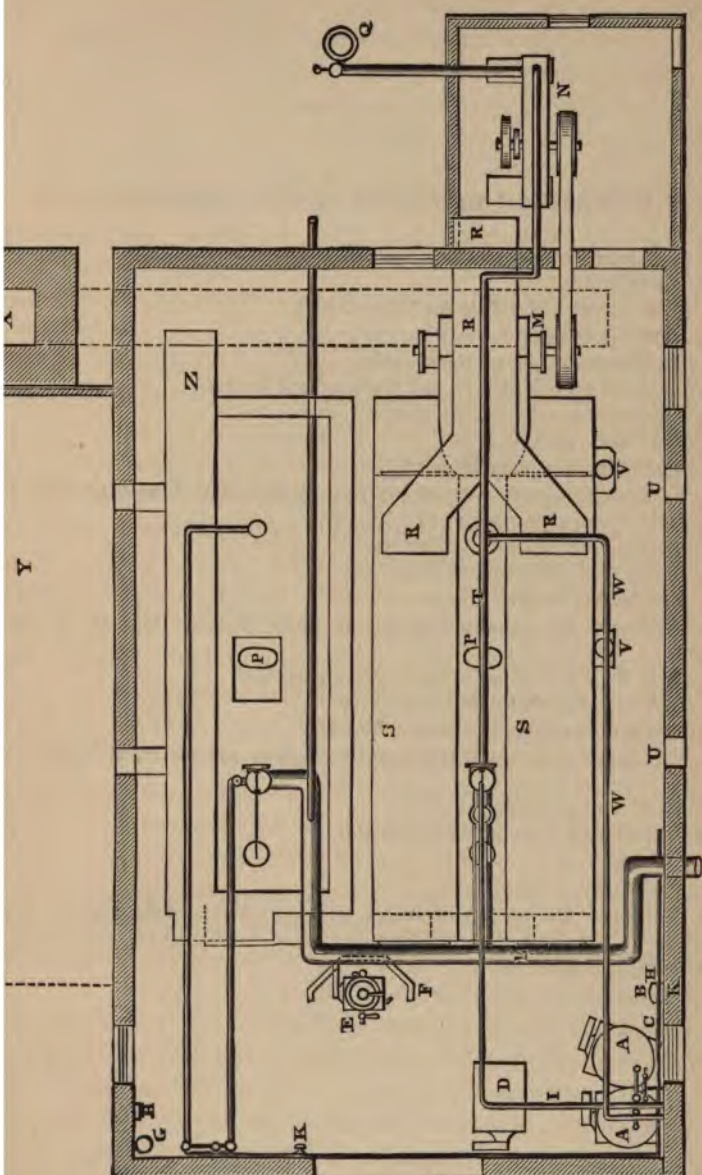

FIG. 1.—GROUND PLAN OF BOILER-HOUSE.

REFERENCES TO GROUND PLAN OF BOILER-HOUSE.

A, A, Water tank on platform scales.
B, Water meter.
C, Water pipes and valves for filling tanks.
D, Platform scales for weighing coal.
E, Calorimeter on its platform scale.
F, Screen to protect calorimeter from radiant heat
G, Edson pressure recording gauge.
H, Test steam gauge.
I, Steam pipe to supply injector.
K, K, Pipe for direct water supply ; not used during these experiments.
L, Main steam pipe : wrapped with felt.
M, Root blower, for exhausting gases.
N, Steam engine to drive blower.
P, Man-hole of boiler.
Q, Condenser for ascertaining the quantity of heat rejected by the steam engine.
R, R, R, R, Cold-air boxes leading to abstractors.
S, S, Abstractors of boiler No. 1.
T, Steam pipe to supply steam engine N.
U, U, Small doors for inserting heat-carriers of pyrometer, at bridge wall and pier.
V, Shelf for pyrometer, at pier.
W, Water pipe from injector to boiler.
X, Chimney.
Y, Coal shed.
Z, Horizontal flue on top of boiler with cold blast : subsequently removed, when the second form of abstractor was applied to this boiler, converting it into warm-blast boiler No. 2.

used to give strength and stability to this overhanging wall; and for the same purpose the rear wall was made 3 feet 4 inches thick.

The boiler to be designated boiler No. 1, warm blast, was precisely similar to the "Pacific" boiler described above, but its setting was in some respects quite different.

The side walls are 33 inches thick, 9 inches being of fire-brick and 24 inches of red brick. This gives room for descending flues on each side, 8 inches in thickness, from the abstractors to the ash-pit, with 9 inches of fire-brick between them and the fire, and 16 inches of red brick outside. These walls are placed 5 feet 6 inches apart, and are plumb all the way up to 1 inch above the axis of the boiler, except a slight contraction of the space between them, of 1 inch on each side, at the fire grates, which are 5 feet 4 inches wide. From the top of these walls, a semicircular arch is sprung over the boiler, leaving a clear space between it and the smaller courses of the boiler of 3 inches at the sides, and 4 inches at the top, into which the hot gases could freely ascend, although no current could pass through. The temperature found in this space at the top—700° to 900° F.—gave at all times a slight degree of superheating, and care was taken to carry the water pretty high in the boiler, to avoid danger of injury to the plates.

At the close of the experiments with this boiler, before turning it over for regular use, large fire-brick tile—18 × 12 × 3 inches—were inserted, one by one, the whole length of the boiler on both sides, just below the arch, closing up the space between the side walls and the boiler, so that there was thereafter no superheating surface in this boiler. The reason for shutting off the superheating surface, when no longer required for experimental purposes, was to guard against overheating the plates.

The space between the rear end of this boiler and the rear wall is closed, or covered, above the flues, by a transverse arch of 5 feet span, 12 inches versed sine and 42 inches radius, resting on corbels brought out 3 inches on each side from the face of the side walls, at about the level of the axis of the boiler. This arch, composed, in fact, of a series of superimposed arches, one fire-brick (4.5 inches) in depth, was carried up even with the intrados of the arch over the boiler, which was continued on over it, to break the joint and to make the brick-work continuous; but was not built up close against the end of the boiler, a space of 0.75 inch being left for difference of expansion between the boiler and the brick-work.

One reason for arching over the boiler in the manner described,

was to obtain a secure foundation for the abstractors. These wer placed on top, one at each side (Fig. 2), leaving a space of 3 fe in width between them, for access to the man-hole, safety valve an other attachments on top of the boiler. Side walls 8 inches thic 32 inches apart, the face of each outside wall flush with the fac of the side wall of the boiler setting, were covered over (after th tubes of the abstractor were put in), by supporting ⊥ bars 8 inch apart, and by 3 courses of brick resting on these bars. The flues f conveying the gases of combustion through the abstractors fro

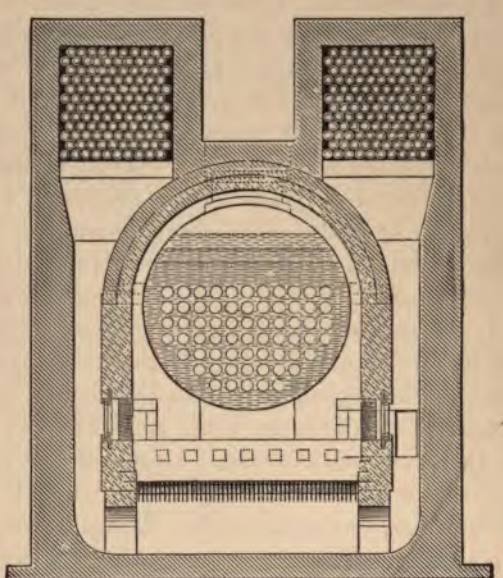

FIG. 2.

CROSS SECTION OF WARM-BLAST BOILER NO. 1, THROUGH FURNACE.

the smoke-bonnet to the blower at the rear of the boiler, are 24 in number—120 in each abstractor—of ordinary lap-welded tube 2 inches in diameter outside and 20 feet long, set by expandin their ends in cast-iron flue sheets provided with suitable flanges f fixing them securely in the brick-work. These 2-inch smoke-flu are set 3 inches apart, between centers, in 12 horizontal rows, 1 tubes in each row, in each abstractor, in equilateral triangles and incased, each one in a 3-inch tube of thin iron, locked spirall leaving between the smoke-flue and the incasing tube an annul space a little less than 0.5 inch in width radially, with pegs pr jecting from the inner flue to keep each tube and its casing in

concentric position. The 3-inch tubes were bedded in mortar, and rested against each other at their lines of contact.

The 3-inch tubes were only 18 feet long—2 feet less than the 2-inch smoke-flues. As the air to pass through the 3-inch tubes, in the annular space between them and the 2-inch smoke-flues, was to be received at the rear end, at the top, and discharged at the front end at the bottom, the rear ends of the upper rows and the front ends of the lower rows of incasing tubes, were set 21 inches from the respective flue sheets; and the front ends of the upper rows, and the rear ends of the lower rows of these same tubes were set 3 inches from the flue sheets; and the ends of all intermediate rows at proportionate distances, in order to facilitate the admission and discharge of air. A cold-air box of thin plate iron, provided with an air-tight damper at its outer end, and branching equally to the two abstractors, supplies air from without the boiler-house at its rear end, and the descending flues in the brick-work already mentioned conduct the warm air from the abstractors to the ash-pit, through arches in the side walls, below the fire grates (Fig. 3).

The gases of combustion are conveyed from the smoke-box to the abstractors at the front end, by a branching smoke-bonnet of ample area (less would be better, causing less radiation), and at the rear they are drawn together again through converging flues to a single descending brick flue leading to the exhausting blower, which discharges directly into the under-ground brick flue leading to the chimney.

Tightly closing dampers are placed in the descending smoke-flue at the rear, and in the descending air-flues at the front, and regulating dampers, like throttle valves, are also placed in these latter. There is also a damper below the exhausting blower, and in line with the descending smoke-flue, which serves, when open, as a "by-pass" to permit the gases to flow to the chimney by natural draft when the blower is not in motion.

Small iron doors, 6 inches square, with isinglass panels, were set in the right-hand side wall, one opposite the bridge wall, the other opposite the pier at the rear end of the boiler, for the insertion and removal of the heat-carriers (platinum balls, in black-lead crucibles), of the platinum-water pyrometers.

In addition to the necessary and proper arrangements heretofore described, there were certain contrivances, destitute alike of merit and novelty, introduced for reasons which it is not necessary to explain.

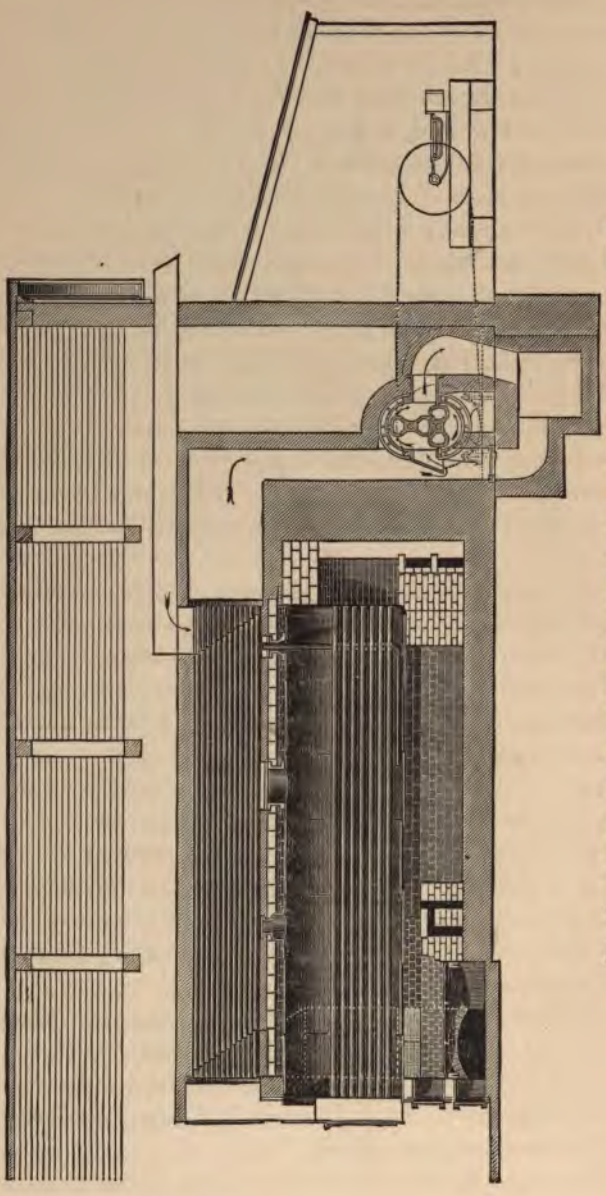

FIG. 3.—VERTICAL, LONGITUDINAL SECTION OF WARM-BLAST BOILER NO. 1.

One of these was a set of perforations in the side walls of the furnace, for the admission of warm air drawn from the descending air flues, *above* the incandescent fuel. Four tiles of fire clay, each 18 inches long, 12 inches wide, and 4 inches thick, each one pierced with 187 holes $\frac{3}{8}$-inch diameter in front and $\frac{5}{8}$-inch in rear, were set, two on each side, end to end, about in the middle of the length of the furnace, and exactly opposite the descending warm-air flues, with their lower edges 12 inches above the fire grates. Sliding "gridiron" dampers, with handles extending out through the arch front, were set behind these perforated tiles and a few inches from them; and great care was taken to make these dampers, when closed, as tight as possible, to reduce to a minimum the harm which the admission of air above the fuel could not fail to do. Careful and repeated experiments and observations proved that these dampers could never be opened without checking the draft through the fuel, and lowering the temperature of the fire; and it is not impossible that a very little leakage through the closed dampers may have lowered in a slight degree the efficiency of the boilers.

Another of these venerable contrivances, which is likely to be tried over and over again every few years till steam engines are no more, was a circuitous flue for heating air, or "superheating" it (whatever superheating may be supposed to mean when applied to a permanent gas), for admission to the combustion chamber through a channel and orifices in the bridge wall, technically known as a "split bridge."

This superheating flue was built entirely within the combustion chamber, back of the bridge wall, extending along the face of the side and rear walls, and was constructed in the following manner:

A wall of fire-brick, 3 inches thick, placed on their edges, three bricks high, was laid on the pavement back of the bridge wall, parallel to the side wall and to the rear end wall, at a distance of 4 inches from these walls. A course of headers 9 inches long was then laid, covering the flue, and bonded 2 inches into the walls, forming a flue 4 inches wide and 13.5 inches high, around the sides and rear of the combustion chamber. On top of this flue, another flue exactly similar was placed, both having their angles at the rear truncated a little, to diminish the resistance. The uppermost of these two flues was connected, just behind the bridge wall, with the vertical air flue on that side, through which warm air descend

from the abstractor to the ash-pit, admission of air to the superheating flue being regulated by a damper hinged at its lower edge in such a manner that when open it extended obliquely into the vertical flue, so as to arrest a portion of the descending warm air and to direct it into the superheating flue. At the opposite end of the bridge wall there was an opening through the horizontal partition between the upper and lower superheating flues, so that the air might descend to the lower flue and return to a point directly beneath the place where it entered the upper flue. Here was an opening into the split bridge; so that after twice making the circuit of the side and rear walls, the air, presumably considerably heated, might pass into the channel in the split bridge, and through small openings in its rear, to mingle with the hot gases flowing over the crest of the bridge wall. Subsequently, an additional wall of fire-brick was laid behind the bridge wall, to turn the superheated air upward.

No good was ever found to result from this system of flues; indeed, it is doubtful if any considerable quantity of air ever passed through the flues at all, although some must have flowed in when the dampers were opened, since the resistance of the open flue, circuitous as it was, could hardly have been so great as that of the coal on the fire grates.

But since the only combustible substance present in the smoke, carbon monoxide (CO), never, in the day-time, exceeded half of one per cent., and rarely exceeded half that small quantity when the dampers were open, for six weeks together, it was impossible that combustion could be sensibly promoted by the admission, at the rear of the bridge wall, of a further supply of air, however much "superheated."

A certain very slight advantage resulted, indirectly, from the interposition of 3 inches more fire-brick, to check radiation where it was most active; but this device and that of perforated tile previously described are here given much in detail in order to show that their uselessness did not result from imperfect design, inadequate extent, or defective construction; but simply from the futility of attempting to burn over again the products of combustion already substantially complete, by the admission of air, however heated, where air, at the temperature of the hot gases themselves, is already in excess by 100 per cent., and most intimately intermixed.

It was assumed at the outset that cast-iron grates could not with-

stand the heat resulting from the introduction of warm blast, and a water grate was provided of a construction supposed to be safe and durable, although costly, consisting of a top and bottom plate, 3 inches apart, united at their edges by a hoop, and having a sufficient number of short tubes set through them for the admission of air. Provision was made for circulation, by a diaphragm in the middle of its width, connecting it with the water space below the flues, and dividing the furnace longitudinally into two equal parts. After repeated trials, this grate leaked so badly that it was discarded, and the ordinary long grates of the Pacific Mills were tried. These were cast two bars together, 5 feet 2 inches long, 0.75 inch thick on top, 0.50 inch at 0.62 below the top, and 0.31 inch at the lower edge; and 5.5 inches deep in the middle. The spaces between grate bars were 0.5 inch, so that the openings, without deduction for obstructions at the ends and at the two intermediate side supports, were equal to 40 per cent. of the whole grate area; and allowance made for all obstructions, the clear space was equal to 34 per cent. These grates, supported at their ends only, were not destroyed by three weeks' use with warm blast; but they gave evidence of injury in places, which made it plain that they might suddenly melt down at any time, and other grates, admitting of more support from below, were tried with entire success. These were the Williams rocking grates, supported on bearers in sections only about 15 inches long, and provided with a means of clearing them by shaking from below, through the ash-pit door. In firing with stationary grates, it was found necessary to keep the fire doors —one at least—open one hour out of ten hours' firing, to clean the fire and draw the clinker. This invariably lowered the temperature all the way from furnace to smoke-box, diminished the draft through the coal on the grates, produced an increased quantity of carbon monoxide (CO), in the chimney gases, and reduced the efficiency of the boiler. With the rocking grates, the time of slicing and cleaning the fire was reduced to ten minutes once a day, at 5.30 P. M. The short, sectional grate bars next to the bridge wall suffered pretty rapid deterioration, and in a less degree those at the front and sides. Some form of grate still better may be found; but it seems probable that the life of any grates, whatever their form, will be less with warm blast than with air taken in at the external temperature—unless, indeed, a water grate can be used. What the excess of cost for grates may be, to offset the gain by warm blast, can only be determined by experience of some duration.

After the conclusion of the experiments with Warm-Blast Boil No. 1 (weeks G & H of Record, ending February 4 and 1 1882), the original Pacific Boiler was converted into Warm-Blas Boiler No. 2, by the simple addition of the abstractors and th air passages and smoke flues necessary to convey the gases throug the abstractors to the exhaust blower, and the air in the opposit direction from without the boiler-house to the ash-pit.

No alteration was made in the boiler; and none in the brick work, otherwise than to build the two vertical flues near the fron end, to conduct the warm blast down to the ash-pit, and into it b arches in the side walls below the fire grates.

These vertical flues occupied, in part, a space of 8 inches orig nally left between the side walls, and, on the left the wall of th boiler-house; on the right the side wall of Warm-Blast Boile No. 1.

The mode of construction first adopted in Warm-Blast Boile No. 1, has been fully described.

The principles involved in that construction were:

1. The division of the air passages into 240 annular channels o uniform cross-section between (*a*) lap-welded smoke flues 2 inche in diameter outside, and (*b*) spiral-locked sheet-iron tubes 3 inche in diameter outside, in order to give uniform velocity to the ai and equal exposure of the air to the warm surfaces.

2. The great addition to the warm surface made by these exte nal tubes, which would be warmed by radiation from the 2-inch flue to almost uniform temperature with them, since air is not sensibl affected by radiant heat. There would therefore be two metalli surfaces in contact with the thin annular stream of air, the inne one 6 inches, the outer 9 inches in circumference, amounting t 300 square feet for each foot in length, and for the whole 20 fee to 6,000 square feet.

3. The skin friction of the 3-inch tube being greater than tha of the 2-inch flue, not alone on account of its 50 per cent. greate area, but also on account of the slightly projecting spiral line o joint within, corresponding with the prominent spiral interlocke ridge on the outside, the air must acquire a rolling motion fro within outward best calculated to bring all parts of the inflowin air into frequent contact with the warm surfaces, and to uniform temperature with those surfaces.

Much apprehension was felt that the smoke might pass in larges volume through the lower courses of 2-inch flues—those first en

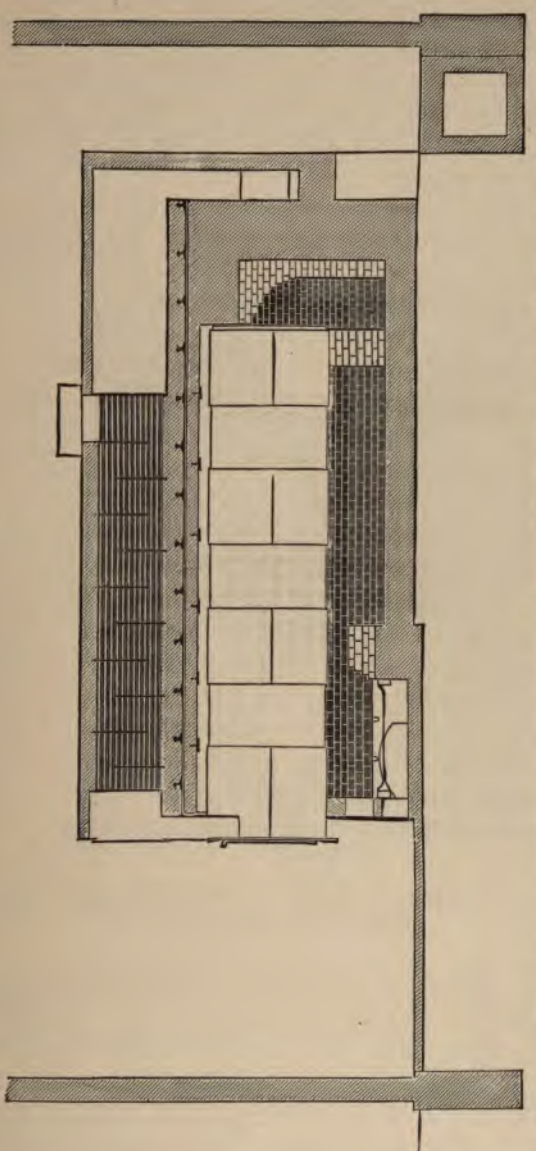

FIG. 4.—VERTICAL, LONGITUDINAL SECTION OF WARM-BLAST BOILER SETTING NO. 2, SHOWING THE DEFLECTORS OF THE ABSTRACTORS.

countered on leaving the smoke-box; and that the air, on the other hand, entering at the top, might flow in greatest volume through the upper annular passages, and that so the effect might be diminished. But extensive and patient probing with the water-platinum pyrometer—the platinum ball being held in the tongs to be described—proved that this apprehension was unfounded—that both air and smoke were at nearly uniform temperature at top and bottom of every cross section.

Yet the quantity of heat transferred from the escaping gases to the inflowing air did not answer expectations based on theoretical

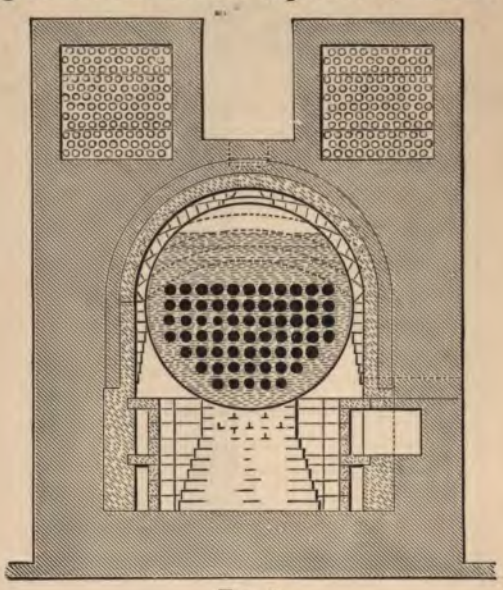

FIG. 5.

CROSS-SECTION OF WARM-BLAST BOILER NO. 1, AT PIER: BUT SHOWING THE ABSTRACTORS OF NO. 2.

considerations. The gases passed off at a temperature about 160° F. above that of the external air, carrying a large quantity of heat to waste. The obstruction sure to arise in time from accumulations of dust in the annular passages, was not lost sight of. The cost, too, of the double pipes, was very considerable. It was therefore decided, after due consideration, to adopt a new mode of construction.

A piece of 2-inch spiral-locked tube, 4 feet long, with brass ferrules soldered into its ends, having been put to severe tests and found air-tight, pipes of that description were adopted for the

smoke flues, at a saving of nearly one-half; and the 3-inch tubes were omitted, and replaced by deflectors, arranged as shown in Figs. 4 and 5. The 2-inch flues were made 18 feet long, of sheet steel, No. 26 American wire gauge (.018 inch thick), each tube formed of a single strip 35 feet 6 inches long and 3.5 inches wide. A ring or ferrule of copper, equal in thickness to the ridge formed by the locked joint (about .054 inch), with its ends cut to the obliquity of the spiral joint, so as to fit closely to it on both sides, made an outer surface at each end smooth and cylindrical, for expansion into suitable holes in the flue sheets; and internal thimbles of lap-welded pipe gave the degree of firmness necessary to hold the expansion.* Partitions of sheet iron, having holes for the 2-inch spiral flues corresponding in position with the holes in the flue sheets, were put into the brick chambers of the abstractors at intervals of about a foot; half of them closed at the top, and extending down to within 3 rows of flues of the bottom of the chamber, and the other half closed at the bottom, and extending up to within 3 rows of the top. Air entering at the top must descend across and among the 2-inch flues, which have spaces of 1 inch between them, pass under the first partitions, or "deflectors," then rise in the same manner across and among the flues to pass over the second deflectors, and so on, until on flowing over the last deflectors, it passes down through the vertical brick flues to the ash-pit.

The deflectors are plain rectangular pieces of sheet iron, No. 18 w. g., set with their side and top (or bottom) edges about 1 inch in the brick-work. The holes are punched, and they cost but a trifle in comparison with the 3-inch spiral air tubes. They also support the flues at every foot of their length, and they allow dust to collect to any probable extent in the corners at the bottom of the brick chambers without causing inconvenience. The deflectors, so far as they go, supply an additional surface warmed by conduction and radiation to impart heat to the air by contact; and the impact of the air in flowing transversely across the flues, although acting in each direction only on about one-half the circumference of each flue, may yet be counted on to give something of that increased effect due to impact of air upon warm surfaces which was first pointed out by Leslie.

For protection against loss by radiation, brick walls and brick covering were used as before; but in order to guard against cracks,

* A better method has since been devised by Mr. F. H. Prentiss, by means of external and internal malleable iron rings.

and to cut off leakage, the whole exterior of the brick-work of the abstractors was incased in thin galvanized sheet iron, locked and soldered.

The covering of the Pacific boiler, described previously, not being strong enough to bear the weight of the abstractors, bars of old rails, equal in length to the width of the boiler setting of warm-blast No. 1 (11 feet), were placed across at intervals of 2 feet, resting on the side walls, and projecting a few inches beyond them. Pieces of ¼-inch plate iron laid from bar to bar on their lower flanges supported the brick-work. After leveling up to the top of the bars, the sheet iron for the bottom of the casing was laid on, a hearth of three courses of brick was laid, the side walls were carried up, and, after the tubes and deflectors were all in proper place, the covering was put on, and the casing of sheet iron completed. A brick flue brought together the two streams of gases from the two abstractors, and conducted the united stream to the exhaust blower.

The results obtained with this apparatus (week I, ending May 20, 1882), were decidedly better than were obtained with the apparatus first tried. With higher temperature of external air, and a smaller quantity of air per pound of coal, the final temperature of escaping gases was reduced 20 degrees lower. Part of this gain may have been due to the manner in which the abstractors are supported, on bars, out of contact with the brick-work (which in the other case was very hot on account of the superheating arrangement), so that less heat was imparted by conduction to the abstractors, to be in part carried off by the smoke. But a part—probably the greater part—was due to the greater efficiency of surface impinged upon by air in motion, over similar surfaces along which air flows smoothly, without impact. Something may be due to the reduced thickness of the metal, but Péclet's formulæ do not lead us to expect a sensible effect from this cause.

The question of durability remains to be settled, but there is now reason, after nearly three years' use, to look for a favorable result. Both the air and the smoke are at a temperature so far above their dew-point—unless, indeed, the boiler leaks badly—that no moisture can be deposited on the flues, either within or without; and there is little danger to be apprehended from sulphur, which in the form of sulphurous acid (SO_2), is not actively corrosive, and of SO_3 (which condensed with water becomes H_2SO_4, or sulphuric acid), there is never much and seldom any. The anthracites contain but very little sulphur, and the Cumberland

bituminous coals only about 0.8 per cent. Picton coal, it is true, sometimes contains sulphur, in the form of iron pyrites, in visibly large quantities.

The cost of the single tubes with deflectors is much less than that of the other form, with double tubes:—*First*, because the spiral steel tubes cost but little more than half as much as the lap-welded tubes of the same size; *second*, because they were reduced from 20 feet in length to 18 feet, yet seemed to be even more efficient; and *third*, because the deflectors cost much less than the 3-inch tubes which they replaced. As to the sheet-iron casing outside of the brick chamber, that was no less desirable with the first form than with the second.

It is probable that the quantity of air per pound of coal consumed was reduced by this air-tight casing, since much air infiltrates through brick-work. The extent of this infiltration is surprising. So great is it that the flame of a match is drawn to and into the interstices of an 8-inch brick wall—not alone at fine visible cracks, but at mortar joints apparently sound.

To cut off this harmful infiltration of air, the outside of the smoke-flues in the rear was coated with desiccated tar and shingled over with tarred cotton cloth. It might be worth while to leave off the outer 8 inches of brick-work of the boiler setting, all around, until the inner portion was complete, and then to cover the whole surface, sides, ends and top (and preferably the bottom also, to keep down moisture), with galvanized sheet iron, locked and soldered. At the arch front, where very pernicious leakage of air is too common, a tight joint could be made by means of a strip of sheet iron riveted to the back side of the arch front all around, to which the casing could be locked and soldered. If, now, the casing were covered with an inch of hair felt, and around and over all 8 inches of brick-work were laid, secured with binders, as usual, or more completely, an appreciable saving of heat would result, perhaps exceeding one per cent. An air space is sometimes left in the brick-work, for the purpose of reducing radiation. Breaking the continuity of the brick-work certainly impedes the outflow of heat, by interrupting conduction, and interposing the slower processes of radiation and absorption; but an air space as an interceptor of radiant heat is futile. Hardly any substance in nature is less useful for this purpose than air, which when dry is absolutely diathermanous. It answers well to build the walls of three successive, independent 8-inch walls, close together, but

not bonded, and free from mortar at their surfaces of contact. Conduction is thereby sensibly interrupted, some freedom is left for unequal expansion, the binders tie all firmly together, and cracks will be less numerous, less continuous, and less disastrous. But all cracks, large and small, should be sedulously stopped up. Very large cracks will often be found between the arch front and the brick-work. These should be stopped with putty. Smoke-box covers and doors, fire doors and ash-pit doors should be carefully fitted, and smoke-box doors and covers, which usually require to be opened but once a week, should be packed or puttied. Fire doors should be made with a groove all around them, to receive a packing of asbestos, and should have some provision for pressing them firmly against their seats on the arch front. However well fitted at first, or when cold, the heat warps them so that they often admit sufficient air to impair the draft where alone draft is useful—through the fuel on the fire grates. For the same reason, the fire door should be left open as little as possible. If the grates are stationary, it will be necessary, with combustion as rapid as 12 pounds of coal per square foot of fire-grate area per hour (counting all the time the draft is open), to clean the fire and draw out clinker as much as six times in ten hours, occupying ten minutes each time, equal to one hour in ten—a serious loss, which may be reduced five-sixths by the use of rocking grates, operated through the ash-pit door. But let no grate-vender quote me as authority for the stereotyped saving of "30 per cent. of 'the coal.'" I believe that an appreciable saving may be made by the use of good rocking grates, perhaps two per cent. In the aggregate, these small savings become important; but aside from the one conspicuous saving by returning to the furnace, in a warm blast, a part of the heat of the gases of combustion after they leave the smoke-box, in some such manner as that herein described, or by its substantial equivalent the Green Economizer, no gain of so much as five per cent. over reasonably good ordinary practice can be so much as fairly hoped for.

II.

Taking up now a second division of the subject, a description will be given of the instruments and apparatus for physical observation.

1. The Pyrometer.—The inner cell, or true containing vessel of this instrument, is 4.25 inches in diameter, and of equal height on the side, with a bottom in the form of the segment of a spherical surface of 4.25 inches radius, all of sheet brass 0.01 inch thick, nickel plated and polished outside and inside (Fig. 6). The outside case is 8 inches in diameter and 8.5 inches deep, of 16 oz.

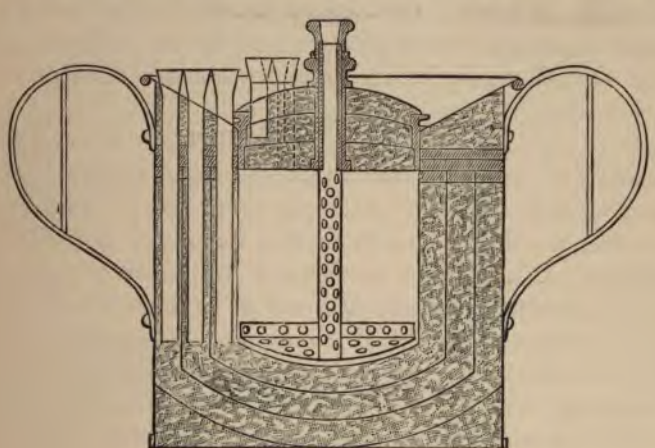

Fig. 6.

WATER-PLATINUM PYROMETER.

copper, nickel plated and polished on the inside but plain outside. There are two handles—on opposite sides—for convenience of rapid manipulation. The top, which is depressed conically like a hopper, is of the same copper as the sides and bottom, and is terminated at its outer edge with a strong wire, forming a lip all around for convenience of pouring. The central cell is connected with the outer case, only by three rings of hard rubber, each 0.25 inch thick; the middle ring completely insulating the cell from its continuation upward to the hopper-shaped top, by interposing its thickness between the flanges of these two parts. The joints formed by contact of these flanges with the hard rubber ring, which

would be likely to leak water into the spaces filled with eider down, were made tight by a coating of asphaltum varnish.

The lower hard rubber ring is, in fact, made up of three concentric rings, each one supporting the flange of a partition. These partitions are complete cups—sides and bottom—of sheet brass 0.01 inch thick, and, together with an additional spherical segment at the bottom, next to the outer case, are nickel plated and polished outside and inside. They divide the space between cell and case into three compartments, each about 0.625 inch in thickness, all filled as are all spaces everywhere, with eider down. All the four plates of the cover are of sheet brass, 0.01 inch thick, nickel plated and polished on both sides; and all are insulated from each other and from the vessel by a hard rubber ring, which forms the outer rim of the cover, and by a tube of hard rubber with a knob and shoulder above and a screw-thread at its lower end, by which the upper and lower plates are firmly held together, while the knob serves for lifting the cover.

Through this tube passes the hollow stem of the agitator, the upper part of it formed of hard rubber, terminated at top by a knob, with a taper hole for a cork, through which a thermometer passes down nearly to the bottom of the stem, the lower part of which is of brass tube. The agitator conforms to the spherical shape of the bottom of the cell, but does not touch it by about 0.25 inch; and has a rim turned up 0.25 inch all around. This agitator and the brass portion of its stem are freely perforated with holes 0.2 to 0.4 inch diameter, and nickel plated and polished. The spherical form of the agitator gives a radial direction to the streams of water passing through its holes when it is raised and lowered, so that very little motion up and down—not enough to lift the hard rubber stem out of its hard rubber incasing tube—suffices to mix the water perfectly.

A slight modification, to the form of a propeller, would enable it to give equally good mixing by rotatory motion, as strongly recommended by Berthelot, and avoid alternate withdrawal and re-immersion of any part of the stem.

Very careful and quite satisfactory determinations were made of the calorific value of the metals directly affected by the temperature of the contained water; and just sufficient water was weighed in, to amount, with the calorimetric value of the instrument, to two pounds of cold water.

This determination was in its general nature similar to the de-

termination of the heat capacity of the calorimeter for testing the quality of steam, fully described elsewhere; but as this instrument was designed to hold only about a quart of water, the method followed was much simpler, and susceptible of greater accuracy.

A tin dipper of about two quarts capacity was used to hold the hot water, which was poured directly into the pyrometer as quickly as possible, whereupon the cover was shut down and the agitator was put in motion. The examples given in the case of the steam-calorimeter will serve as a type of the experiments with the pyrometer; but in this latter case a special correction was demanded. The cooling of the hot water was augmented by pouring, in consequence of the exposure to the air of a large surface of water in a thin sheet. The effect of this exposure was ascertained in the following manner: The instrument was placed in a bath of tepid water, so as to bring the temperature of all the materials composing it exactly to the temperature of the water to be poured in. Thus, whatever diminution of temperature the latter might suffer, must be entirely due to the loss of heat by pouring. Four experiments, carefully made, gave the following results: Loss of temperature by pouring, at 170° F., 0.81°, 0.86°, 1.00°, and 1.07°; mean, 0.935° F.

The following six values of the calorific capacity of the metals of the pyrometer, which share directly the temperatures of the inclosed water, including also the thermometer used with the instrument, were found by experiment: 0.1048, 0.1052, 0.1077, 0.1008, 0.1028, 0.1104.

Mean,	0.1053,	=	0 lbs.	1 oz.	11 drms.
Add water,	1.8947,	=	1	14	5
	2.0000,	=	2	0	0

This mean was the value used. The instrument being put on delicate coin scales and counterbalanced, weights equal to 1.8947 pounds avoirdupois, = 1 lb. 14 oz. 5 drms., were added to the counterbalancing weights, and cold water was poured in until the scales again balanced.

The vessel and its contents were then just equal in heat capacity, while the temperature of the water was not above 38° F., to 2 pounds of cold water.

The heat-carriers were platinum balls, of three sizes:

1 of 4,200 grains	=	0.6 lb. avoirdupois.
1 of 2,800 grains	=	0.4 lb. "
1 of 1,400 grains	=	0.2 lb. "

Two vessels exactly similar were provided, and when duplicate observations were made for mutual verification, the two smaller balls were placed in one crucible, and the larger one, equal in weight to the two smaller ones, in the other. As the two instruments were sensibly alike, simultaneous observations with similar exposure should give, as they usually did give, temperatures equal within the limit of error to be expected—less than 10° F.—and occasionally identical temperatures.

Sometimes one of the smaller balls was used alone, to avoid raising the water to a final temperature above the range of a delicate thermometer embracing only a few degrees, of half to five-eighths inch to 1 degree, graduated to 0.1 degree.

The scale of the pyrometer, for the first approximation, was for the larger ball (and for the two smaller balls together), 100° to 1°; for the middle sized ball, 150° to 1°; and for the smaller, 300° to 1°. In order to ascertain what correction, if any, should be made for cooling during the process of withdrawing the platinum balls from the fire and immersing them in the water of the pyrometer, several experiments were made upon the effect of cooling from 15 to 35 minutes. The fire-brick, charged with its two crucibles without the covering brick, but with the covers of the crucibles in place (Figs. 7 and 8, p. 37), was withdrawn from the fire in the usual manner, and the ball from one of the crucibles was put as quickly as possible into one of the pyrometers, and the notes were taken. The other crucible was then permitted to stand in the fire-brick, with its cover on, but exposed to the air of the room, usually 15 minutes, sometimes 25 minutes, and in one case 35 minutes, when the balls from the crucible in question were put into the other pyrometer, and the notes were taken as before.

When the two crucibles were emptied of their balls into the two pyrometers as quickly as possible, there were often discrepancies of 10°, 25°, or 50°, although accordance within 10° or less was frequent. These discrepancies resulted partly from errors of observation, and partly, no doubt, from real difference of temperature; and the apparent differences resulting from difference in the time of exposure to the air were therefore mixed up with errors of observation, and with possible differences of original temperature. The mean cooling effect was 0.7° F. per minute, equal to 70° F. in the resulting temperature; and the range was from 1.2° to 0.2°, say 120° to 20° in the result. At all events it was small, and although most active at first, while the heat was greatest, the loss

was too small to require notice when the balls were immersed in the water of the pyrometer in 3 to 5 seconds from the time of opening the door to withdraw the fire-brick with its crucibles; as was usually the case when there was no accidental detention.

THE USE OF THE PYROMETER.

In using this instrument we have, in order to obtain the first approximation, to make two assumptions: 1st, That the specific heat of the water at the temperatures employed, will be constant, and equal to 1.00000; 2d, That the specific heat of the platinum balls employed will be constant, and equal to 0.03333, that is, to $\frac{1}{30}$ that of the water.

Since the largest platinum ball weighs three-tenths (0.3), as much as the water (including in all cases the heat value of the instrument), it follows from the above assumptions that the heat capacity of the platinum ball will be one one-hundredth (0.01), of that of the water, including the inclosing vessel. Every degree, then, added to the temperature of the water indicates roughly 100° lost by the platinum ball. The error resulting from the inaccuracy of the first assumption is small, and may sometimes be neglected; but with high temperature, where the range of temperature in the water is considerable, and especially when the initial temperature of the water is as high as 40° F., it is better to eliminate the error by the use of the following table of temperatures and corresponding British thermal units. For instance, if the initial temperature be 61°, and the final, 83°, the number of British thermal units added to the water will be:

$$83.041 - 61.010 = 22.031;$$

and the loss of heat by the platinum ball, on the second assumption will be:

$$22.031° \times 100° = 2203.1° \text{ F.}$$

TABLE NO. II.

Temperatures Fahrenheit, and corresponding number of British thermal units contained in water, from zero Fahrenheit.

Deg.	B. t. u.	Deg.	B. t. u.	Deg.	B. t. u.	Deg.	B. t. u.
32	32.000	57	57.007	82	82.039	107	107.101
33	33.000	58	58.007	83	83.041	108	108.104
34	34.000	59	59.008	84	84.043	109	109.107
35	35.000	60	60.009	85	85.045	110	110.110
36	36.000	61	61.010	86	86.047	111	111.113
37	37.000	62	62.011	87	87.049	112	112.117
38	38.000	63	63.012	88	88.051	113	113.121
39	39.001	64	64.013	89	89.053	114	114.125
40	40 001	65	65.014	90	90.055	115	115.129
41	41.001	66	66.015	91	91.057	116	116.133
42	42.001	67	67.016	92	92.059	117	117.137
43	43.001	68	68.018	93	93.061	118	118.141
44	44.002	69	69.019	94	94.063	119	119.145
45	45.002	70	70.020	95	95.065	120	120.149
46	46.002	71	71.021	96	96.068	121	121.153
47	47.002	72	72.023	97	97.071	122	122.157
48	48.003	73	73.024	98	98.074	123	123.161
49	49.003	74	74.026	99	99.077	124	124.165
50	50.003	75	75.027	100	100.080	125	125.169
51	51.004	76	76.029	101	101.083	126	126.173
52	52.004	77	77.030	102	102.086	127	127.177
53	53.005	78	78.032	103	103.089	128	128.182
54	54.005	79	79.034	104	104.092	129	129.187
55	55.006	80	80.036	105	105.095	130	130.192
56	56.006	81	81.037	106	106.098	131	131 197

The error arising from the inaccuracy of the second assumption is much more important, but is easily eliminated—at least approximately—by the use of Table III., which is carried out for every 100° F., with certain intermediate points, for reference:—32° and 212°, for verification of the pyrometer by these standard temperatures—melting ice and boiling water.

At 446.2° F. the assumption of $0.03\dot{3}\dot{3}$ for the specific heat of platinum is correct. At lower temperatures the correction is *minus:* at all higher temperatures it is *plus.* The use of the table is obvious. Having found the approximate observed loss of temperature, corrected for variations in the specific heat of water, look for the nearest corresponding loss in column 6, "observed loss of temperature" etc., and if not found exactly, find the intermediate point by the aid of the proper difference in column 7. Opposite, in column 1, will be found the true loss of temperature by the heat-carrier, corresponding to the observed loss. For instance, having found an

observed loss of temperature, corrected for variation of specific heat of water, = 2203.1°, we find in column 6, 2152.1 which subtracted from 2203.1, leaves 51.0; and the tabular difference for 100° being 131.7 = 1.317 for 1°, 51 divided by 1.317, gives 38.7. Turning now to column 1, we find opposite 2152.1, 1900; and adding 35.1 we have 1938.1 as the (approximately) true loss of heat by the carrier in cooling from initial temperature to 83° F., and 1938 + 83 = 2021° F. as the initial temperature of the heat-carrier on its immersion in the water of the pyrometer.

The manner of manipulating the platinum balls as heat carriers, is plainly indicated in Fig. 7. In most cases the covering brick may be omitted; but it should be used whenever, on account of obstacles in the way of rapid manipulation, more than four or five seconds are required to remove the crucibles from the fire and to immerse the balls in the water.

For observations in the heart of the fire, the crucibles may be used without the brick. No bits of coal must be permitted to enter the crucibles; and this accident may be guarded against in some measure by binding on the covers with copper wire wound many times around. The wire will be speedily melted, but will endure long enough fairly to insert the crucibles and cover them with the glowing coal; and, with care, they may be taken out without disturbing their covers. Thermometers should be delicate, not less than 0.3 inch to 1°, and graduated to tenths of a degree.

They may then be read to hundredths, and temperatures may be determined within a very few degrees.

It will be apparent, on reflection, that these tables can give only approximate results, and could be exact only upon the impracticable condition that the final temperature of the water and heat carrier, after the immersion and cooling of the latter, should be, in every case, 32° F.

But since the initial temperature must always be above this point, and the final temperature several degrees higher still, while the tables are based on the mean specific heat of platinum, or, with the compound balls—platinum and iron—between 32° and the respective higher temperatures included in the table, an error will result from the use of the tables, varying in magnitude with the number of degrees between 32° and the final temperature. To be exact, the tables should be expanded so as to embrace specific heats between 32° and, say, 100° F., varying by single degrees, or by small intervals—3° or 5°—at the lower limit; and 100°, 200°, 300°,

etc., as in these tables, for the upper limit. Such tables would be cumbrous and inconvenient, and by no means worth while. The approximation given by the tables is pretty close, and may usually be made satisfactory. In most cases a rather closer approximation may be made by adding the number of degrees of final temperature of the water to the observed loss of heat by the heat-carrier, *before* correction by the table, as already described. Thus, 2203.1 + 83.0 = 2286.1, corresponding, in Table III., to 2001.7°.

A still closer approximation may be made by subtracting 32° from the number of degrees of final temperature, and reducing the difference to *pyrometer degrees*, by multiplying it by the tabular difference, 0° to 100°, column 7, Table III., which is 96.9 for 100°, = .969 per degree. The pyrometer degrees so found are to be added to the observed loss of heat by the heat-carrier, and the corresponding true loss is to be taken out of the table; and 32 added to this will give a close approximation to the true temperature of the hot ball.

Thus, 83 − 32 = 51, and 51 × .969 = 49.4, and 2203.1 + 49.4 = 2252.5.

The next smaller tabular number in column 6 is 2152.1, and 2252.5 − 2152.1 = 100.4, and 100.4 ÷ 1.317 (131.7 ÷ 100 = 1.317) = 76.23. The number in column 1, opposite 2152.1 is 1900, and 1900 + 76.23 + 32 = 2008.2° = the true temperature sought—to a close approximation. The respective values found by the three methods are 2021°, 2002°, and 2008°, showing an extreme range of variation at this high temperature, of less than 1 per cent.

Either method will usually be accurate enough. The first and second are equally easy of application, the third but little more laborious. Should more exact results be desired, the formula for specific heat may be used.*

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* For a discussion of the specific heat of platinum and iron, at various temperatures, or, more properly, the mean specific heat of these metals from 32° F. to higher temperatures, see "Journal of the Franklin Institute," Vol. LXXXIV., third series, July–December, 1882, pp. 91, 169, and 252. Also, "Transactions of the American Society of Mechanical Engineers," Vol II., p. 42; and Vol. III., p. 174.

TABLE III.

Temperatures in deg. Fahr. corresponding with specific eats in column 2.	Mean sp. ht. of Platinum from 32° computed for each 100 deg. Fahrenheit.	Differences of sp. ht. for each 100° F.	Ratio of computed to assumed sp. ht.: viz. 1-30 water = 0.033333.	Differences of Ratios for each 100° F.	Observed loss of temperature by heat-carrier in cooling: at assumed ratio H_2O 30 to Pt 1.	Differences of observed loss per 100° Fahr.
1	2	3	4	5	6	7
0	.031983		.95950		0.0	
32	.032080	303	.96240	907	30.8	96.9
100	.032286	302	.96857	907	96.9	98.6
200	.032588		.97764		195.5	
212	.032624	303	.97873	908	207.5	100.5
300	.032891	303	.98672	908	296.0	102.3
400	.033193		.99580		398.3	
446.195	.033333	303	1.00000	909	446.2	104.1
500	.033496	304	1.00489	910	502.4	106.0
600	.033800	303	1.01399	910	608.4	107.8
700	.034103	303	1.02309	910	716.2	109.6
800	.034406	304	1.03219	911	825.8	111.4
900	.034710	304	1.04130	912	937.2	113.2
1000	.035014	304	1.05042	912	1050.4	115.1
1100	.035318	304	1.05954	913	1165.5	116.9
1200	.035622	305	1.06867	913	1282.4	118.7
1300	.035927	304	1.07780	914	1401.1	120.6
1400	.036231	305	1.08694	914	1521.7	122.4
1500	.036536	305	1.09608	915	1644.1	124.3
1600	.036841	305	1.10523	915	1768.4	126.1
1700	.037146	305	1.11438	916	1894.5	127.9
1800	.037451	306	1.12354	917	2022.4	129.7
1900	.037757	306	1.13271	917	2152.1	131.7
2000	.038063	305	1.14188	917	2283.8	133.4
2100	.038368		1.15105		2417.2	

TABLE III.—*Continued.*

Temperatures in deg. Fahr. corresponding with specific heats in column 2.	Mean sp. ht. of Platinum from 32° computed for each 100 deg. Fahrenheit.	Differences of sp. ht. for each 100° F.	Ratio of computed to assumed sp. ht.: viz. 1-30 water = 0.033333.	Differences of Ratios for each 100° F.	Observed loss of temperature by heat-carrier in cooling: at assumed ratio H_2O 30 to Pt 1.	Differences of observed loss per 100° Fahr.
1	2	3	4	5	6	
		306		918		135.3
2200	.038674		1.16023		2552.5	
		307		919		137.2
2300	.038981		1.16942		2689.7	
		306		919		139.0
2400	.039287		1.17861		2828.7	
		307		920		140.8
2500	.039594		1.18781		2969.5	
		306		920		142.7
2600	.039900		1.19701		3112.2	
		307		921		144.6
2700	.040207		1.20622		3256.8	
		307		921		146.4
2800	.040514		1.21543		3403.2	
		308		922		148.3
2900	.040822		1.22465		3551.5	
		307		923		150.1
3000	.041129		1.23388		3701.6	
		308		923		152.0
3100	.041437		1.24311		3853.6	
		308		923		153.9
3200	.041745		1.25234		4007.5	
		308		924		155.7
3300	.042053		1.26158		4163.2	
		308		925		157.6
3400	.042361		1.27083		4320.8	
		308		925		159.5
3500	.042669		1.28008		4480.3	
		309		926		161.3
3600	.042978		1.28934		4641.6	
		309		926		163.2
3700	.043287		1.29860		4804.8	
		309		927		165.1
3800	.043596		1.30787		4969.9	
		309		927		166.9
3900	.043905		1.31714		5136.8	
		309		928		168.8
4000	.044214		1.32642		5305.6	

Table IV., which follows, constructed in the same manner as Table III., but for iron instead of platinum, as a heat-carrier, requires no special explanation, as the use of the two tables is altogether similar. Iron can be used at all only at moderate temperatures, and the results obtained by its use must be crude, on account of its rapid change of weight by oxidation. Table V. contains

three columns of corrections: first, for platinum, corresponding to column 6 of Table III.; second, for iron, corresponding to column 8 of Table IV.; and third, for a compound ball, composed of 700 grains of fine wrought iron encased in 700 grains of platinum, formed into a solid capsule, about 0.048 inch thick; the whole weighing 1,400 grains, with a heat capacity (at the assumptions for specific heat, for Pt, 0.03333̇, for Fe, 0.16666̇), equal to that of 4,200 grains = 0.6 lb. of platinum. The assumed specific heat of Fe being five times that of Pt (0.03̇3̇ × 5 = 0.16̇6̇), the 700 grains

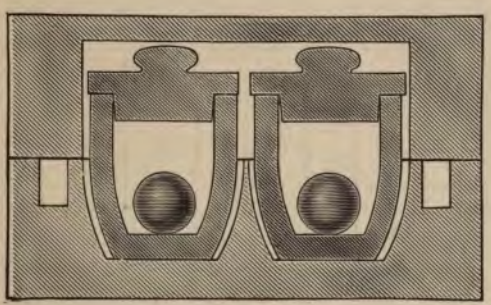

FIG. 7.

PLATINUM BALLS, CRUCIBLES AND FIRE-BRICK BED AND COVER, AS ARRANGED FOR USE WITH THE WATER-PLATINUM PYROMETER.

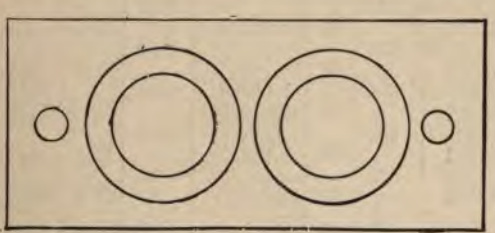

FIG. 8.

TOP VIEW OF LOWER FIRE-BRICK.

of Fe are equal to 3,500 grains of Pt, and 700 grains added for the Pt cover, the total is 4,200.

I had two of these compound balls, and often used them at moderate temperatures, 1,000° to 1,200° F., in direct comparison with solid platinum balls, without detecting any important discrepancies in the results. The advantage of the platinum cover is that the iron is protected from oxidation. The advantage of the iron is that there is great saving of cost.

TABLE IV.

FOR IRON HEAT-CARRIER: ASSUMED SP. HT. $= 0.16\dot{6}$.

Temperatures in deg. Fahr., corresponding with specific heats in column 2.	Mean sp. ht. of Iron, from 32° F., computed for each 100° F.	Differences of sp. ht. for each 100°.		Ratio of computed to assumed sp. ht., viz.: $\frac{1}{6}$ water = 0.166663.	Difference of ratio for each 100°		Observed loss of temperatures by heat-carrier at assumed ratio, H_2O to Fe, 6 to 1.	Differences of observed loss:	
		1st diff.	2d diff.		1st diff.	2d diff.		1st diff.	2d diff.
1	2	3	4	5	6	7	8	9	10
0	.10587			.63524			0.0		
32	.10687	328		.64122	1966		20.5	65.5	
100	.10915		47	.65490		287	65.5		4.5
		375			2253			70.0	
200	.11290		48	.67743		285	135.5		5.3
212	.11339	423		.68032	2538		144.2	75.3	
300	.11713		48	.70281		285	210.8		6.3
		471			2823			81.6	
400	.12184		47	.73104		287	292.4		7.1
		518			3110			88.7	
500	.12702		48	.76214		284	381.1		7.8
		566			3394			96.5	
600	.13268		47	.79608		287	477.6		8.9
		613			3681			105.4	
700	.13881		48	.83289		285	583.0		9.6
		661			3966			115.0	
800	.14542		48	.87255		285	698.0		10.6
		709			4251			125.6	
900	.15251		47	.91506		287	823.6		11.2
		756			4538			136.8	
1000	.16007		48	.96044		284	960.4		12.3
1082.5	.16667	804		1.00003	4822		1082.5	149.1	
1100	.16811		47	1.00866		287	1109.5		13.1
		851			5109			162.2	
1200	.17662		48	1.05975		285	1271.7		13.9
		899			5394			176.1	
1300	.18561		48	1.11369		285	1447.8		14.8
		947			5679			190.9	
1400	.19508		47	1.17048		287	1638.7		15.6
		994			5966			206.5	
1500	.20502		48	1.23014		284	1845.2		16.5
		1042			6250			223.0	
1600	.21544		47	1.29264		287	2068.2		17.4
		1089			6537			240.4	
1700	.22633		48	1.35801		285	2308.6		18.2
		1137			6822			258.6	
1800	.23770		48	1.42623		285	2567.2		19.1
		1185			7107			277.7	
1900	.24955		47	1.49730		286	2844.9		19.9
		1232			7394			297.6	
2000	.26187			1.57124			3142.5		

TABLE V.

FOR HEAT-CARRIERS OF PLATINUM, IRON, ETC. (Pt, Fe).

True temperatures in deg. Fahr., corresponding with observed temperatures in columns 2, 5, and 8.	Observed loss of temperature by Platinum heat-carrier at assumed ratio of sp. ht. H_2O to Pt, 30 to 1.	Differences of observed loss for each 100° Platinum.		Observed loss of temperature by Iron heat-carrier, at assumed ratio of sp. ht. H_2O to Fe, 6 to 1.	Differences of observed loss for each 100° Iron.		Observed loss of temperature by comp'nd heat-carrier, at assumed ratios of sp. ht. Pt, $\frac{1}{30}$. Fe, 6.	Differences of observed loss for each 100°. Pt and Fe.	
		1st diff.	2d diff.		1st diff.	2d diff.		1st diff.	2d diff.
1	2	3	4	5	6	7	8	9	10
0	0			0			0		
32	30.8	96.9		20.5	65.5		22.2	70.7	
100	96.9		1.7	65.5		4.5	70.7		4.1
		98.6			70.0			74.8	
200	195.5		1.9	135.5		5.3	145.5		4.7
212	207.5	100.5		144.2	75.3		154.8	79.5	
300	296.0		1.8	210.8		6.3	225.0		5.6
		102.3			81.6			85.1	
400	398.3		1.8	293.4		7.1	310.1		6.1
446.2	446.2	104.1			88.7			91.2	
500	502.4		1.9	381.1		7.8	401.3		6.9
		106.0			96.5			98.1	
600	608.4		1.8	477.6		8.9	499.4		7.7
		107.8			105.4			105.8	
700	716.2		1.8	583.0		9.6	605.2		8 3
		109.6			115.0			114.1	
800	825.8		1.8	698.0		10.6	719.3		9.1
		111.4			125.6			123.2	
900	937.2		1.8	823.6		11.2	842.5		9.7
		113 2			136.8			132.9	
1000	1050.4		1.9	960.4		12.3	975.4		10.5
1060	1119.5	115.1		1048.4	149.1		1060.2	143.4	
1082.5	1145.9			1082.5		13.1	1093.1		11.3
1100	1165.5		1.8	1109.5			1118.8		
		116.9			162.2			154.7	
1200	1282.4		1.8	1271.7		13.9	1273.5		11.8
		118.7			176.1			166.5	
1300	1401.1		1.9	1447.8		14.8	1440.0		12.7
		120.6			190.9			179.2	
1400	1521.7		1.8	1638.7		15.6	1619.2		13.3
		122.4			206.5			192.5	
1500	1644.1		1.9	1845.2		16.5	1811.7		14.0
		124.3			223.0			206.5	
1600	1768.4		1.8	2068.2		17.4	2018.2		14.9
		126.1			240.4			221.4	
1700	1894.5		1.8	2308.6		18.2	2239.6		15.4
		127.9			258.6			236.8	
1800	2022.4		1.8	2567.2		19.1	2476.4		16.2
		129.7			277.7			253.0	
1900	2152.1		2.0	2844.9		19.9	2729.4		17.0
		131.7			297.6			270.0	
2000	2283.8			3142.5			2999.4		

The apparatus for heating platinum heat-carriers for the pyrometer consists of two black-lead crucibles, 2 inches inside diameter at the top, and 3 inches deep, with suitable covers, as shown in Figs. 7 and 8, which are set into cavities in molded fire-brick, to avoid danger of accidental overturns. Platinum balls, each weighing 0.6 lb. avoirdupois (4,200 grains = 272.16 grammes), or one such ball, and two of 4,200 grains aggregate weight, are placed in the two crucibles—4,200 grains in each—covered up, and submitted to the heat in the desired exposure, long enough to insure uniform heating throughout. If the temperature fluctuates, as in most exposures will be likely to happen, the fire-brick and crucibles will in some degree integrate the fluctuations during the period of exposure.

For moderate temperatures, not exceeding a low red heat, and in situations not admitting of the use of crucibles, a pair of tongs was used, four or five feet in length, of steel, quite slender, with the extremities of their jaws concave, of suitable form and size to receive and cover the platinum ball. A link slipped over the handles held the ball securely, and permitted it to be put into places otherwise inaccessible, kept there until heated, and then withdrawn quickly and released to the water of the pyrometer. The temperature of flue gases, and of the warm blast, determined in that way, agreed substantially with the readings of mercurial thermometers, in cases where these could be satisfactorily used. The temperature of the brick deep in the wall—near the inside, where the heat was too great for glass thermometers—was obtained in this manner. Many temperatures ascertained by the use of this instrument, in the fire, at the bridge wall, at the pier, and in the arch over warm-blast boiler No. 1, will be found under the proper head.

2. The Calorimeter.—This instrument, shown in section in Fig. 9, was the result of much study, and answered fairly the expectations formed of it.

The lining, which is the true containing vessel, is of 24 oz. tinned copper, 17 inches in diameter and 32 inches deep, with a rim at the top 2.25 inches wide, of the same copper; and weighs, complete, 27 lbs. avoirdupois. This was surrounded, sides and bottom by a case of galvanized iron (Fe and Zn), 18.5 inches in diameter, 32.75 inches deep, No. 26 Birmingham wire gauge, weighing 15.5 pounds. A second case surrounds this 20 inches in diameter and 33.5 inches deep, of galvanized iron No. 26 w. g., weighing 16.1 pounds. An outside case surrounds all, 21.5 inches

in diameter and 34.25 inches deep, of galvanized iron No. 18 w. g., weighing, with its handles, 48 pounds. There are, therefore, three chambers, each 0.75 inch thick, all around, sides and bottom, the outer one of which is filled with hair felt, the two others with eider down. There is a cover, also in three compartments, filled in the same manner. The lower compartment of the cover is a little less than 17 inches in diameter, and freely enters the 17-inch inner chamber; the other two are 21.5 inches in diameter, and extend

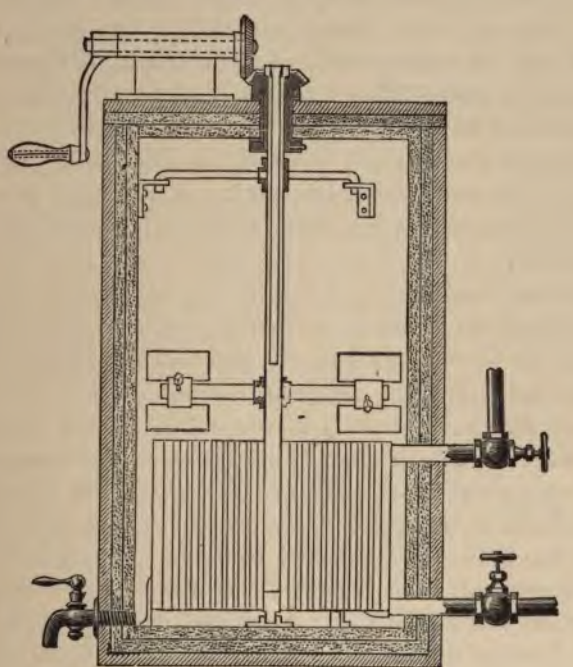

FIG. 9.

CALORIMETER.

out flush with the outside of the case. The lower plate of the cover, and the cylindrical band around the lower third, are of 24-ounce tinned copper, and weigh 3 pounds. This copper lining of the calorimeter and of its cover, is supposed to follow closely all the changes of temperature of the inclosed water, and to be to a considerable degree insulated from the exterior parts, and from the outer air.

A steam surface condenser, 15 inches in diameter and 12 inches high, is set inside, on short legs with broad, flat feet, near the

bottom of the 17-inch chamber; so that there is a space of 1 inch beneath it and all around it.

The cylindrical case of this condenser is of sheet copper, 0.18 inch thick, and the heads are of cast brazing copper of the same thickness, all united by brazing. There is a 2-inch brass tube in the middle; and 144 brass tubes, .75 inch outside diameter, are set by expanding, and sealed air-tight with soft solder, which is always, when the instrument is in use, immersed in cool water. This drum, or condenser, will safely bear an internal pressure of 200 pounds per square inch. Steam is admitted into it by a 0.75-inch brass pipe near its upper end; and water resulting from condensation of steam is drawn off by a similar pipe placed so low as to completely drain the lower head. Both of these pipes are made tight where they pass through the walls of the calorimeter, and each is provided with a screw-valve stop-cock. A 0.75-inch pipe, with a Bibb cock, is inserted in the barrel of the calorimeter, to draw the water out of it.

The agitator, for insuring uniformity of temperature throughout the contents of the calorimeter, is constructed as follows: A brass pipe 1 inch in diameter, about 34 inches long, freely perforated with holes 0.375 inch in diameter, having at the lower end a pivot to rest in a suitable step at the bottom of the barrel, passes down through the 2-inch tube of the condenser, and rises, when resting in its step, to about the level of the top of the cover when in place. A light three-legged spider, supported by light brass ears riveted to the lining of the barrel near the top, and having in the middle a short brass tube loosely fitting the tubular shaft, steadies the upper end of this shaft in an upright position when the cover is removed, and gives rise to no constraint when the cover is on.

The cover has a bushing in the center through which passes the hollow hub of a miter gear of 4 inches pitch diameter, fitted to slip over the upper end of the tubular shaft when the cover is placed on the barrel. This miter gear is held in its place in the cover by a collar on the lower end of its hub below the cover. It is loose on the tubular shaft—which it is designed to turn—but is at once locked to it by the insertion of a thermometer-case, the upper end of which is provided with a stopple fitting the tubular shaft, and fitted with two wings which pass through slots in the upper end of the tubular shaft, and engage with corresponding key-seats in the hub of the miter gear, locking gear and shaft together. A pipe box, having a stand and foot riveted to the cover, carries a short

horizontal shaft, on which, at the inner end, is a miter gear engaging with the one on the upright tubular shaft; and at its outer end a crank, by means of which it may be turned, giving motion to the tubular shaft.

A brass collar, fitted to slide on the shaft, carries two arms of brass tube, 0.625-inch diameter, screwed into the collar, serving as set-screws, to fix the collar at any desired height, and as supports for vanes to agitate the water. These arms are about 7 inches long, and extend to within about an inch of the lining of the barrel. The vanes have two blades, each secured to hubs which slide and turn freely on the arms, and may be set in any desired position, and at any desired angle, by set-screws. These vanes may, therefore, be considered as propeller blades, which in turning in the proper direction give an upward motion to the water at the outer part of the space it fills, accompanied, of course, by an equal downward motion in the middle; and produce a circulation most conducive to equalization of temperature, without any alternate withdrawal and re-immersion of any part of the apparatus, which must always be attended by some loss of heat. Some improvement could be made, particularly by reducing the weight of certain parts, such as the steam condenser, especially for low pressures—under 120 pounds per square inch; but the general principles are believed to be sound, and the operation was fairly satisfactory.

It should be mentioned that blocks of dry pine wood were placed in the spaces at the bottom, under the feet of the condenser, to support the heavy weight of this part; yet this weight and the feet which support it are a source of great anxiety in moving the instrument, especially in shipping it long distances by rail, lest the feet should cut through the light copper lining of the barrel. A better plan would be to support the condenser on molded blocks of hard rubber of sufficient size to distribute the weight.

It was necessary to ascertain the number of pounds of water which might be taken as the equivalent of so much of the metal of the instrument as must be assumed to follow promptly all changes of temperature in the contained water. Three methods were pursued for this purpose:

1st. By direct calculation from the known weight and specific heat of the metals so situated;

2d. By drawing into the calorimeter, cooled down to a low temperature, a weighed quantity of water of a known higher temperature, and observing the resulting temperature—the method of mixture;

3d. By condensing a weighed quantity of steam of known pressure and temperature, known also to be dry saturated steam, because drawn from a quiescent boiler; with a weighed quantity of water of known temperature in the barrel—again the method of mixture.

By the first method we obtain:

TABLE VI.

EFFECTIVE HEAT VALUE OF THE CALORIMETER.

NAMES OF METALS.	Weight Pounds.	Specific heat.	Effective heat value: B. t. u.
Copper	171.80	.095	16 32
Tin	1.25	.057	.07
Brass	8.31	.094	.70
Soft solder, Sn 2, Pb 1	2.09	.048	.10
Totals	183.45	.0937	17.19

The mean sp. ht. of the mass, at the usual temperatures, is therefore $\frac{17.19}{183.45} = .0937$.

By the second method:

We have first to ascertain the limits of error in drawing off and weighing water from the steam condenser, as follows:

FIRST TRIAL.

Weight of water poured in	lbs.	11.80176
Weight of water drawn out	"	11.82324
Apparent excess drawn out	"	0.02148
Ratio of excess	per cent.	0.1818

SECOND TRIAL.

Weight of water poured in	lbs.	11.82129
Weight of water drawn out	"	11.79785
Apparent deficit drawn out	"	0.02344
Ratio of deficit	per cent.	0.1985

THIRD TRIAL.

Weight of water poured in	lbs.	11.80566
Weight of water drawn out	"	11.82324
Apparent excess drawn out	"	0.01758
Ratio of excess	per cent.	0.1483

Combining the errors of the three trials, we obtain:

TABLE VII.

ERRORS OF POURING IN, DRAWING OUT, AND WEIGHING.

	POUNDS.	OUNCES.	PER CENT.
First error..... +	0.02184	0.349	0.1818
Second error. ... —	0.02340	0.374	0.1985
Third error..... +	0.01758	0.281	0.1483
Means.....	0.02092	0.335	0.1762

It will be seen that the errors are in opposite directions, and that they include errors of pouring in and of drawing out; and of two weighings. The error of drawing out and one weighing, is therefore less than one-third of an ounce, less than one-fiftieth of a

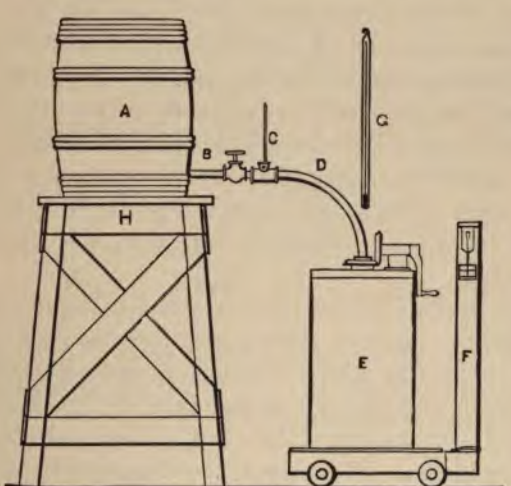

FIG. 10.

APPARATUS FOR TESTING THE HEAT CAPACITY OF THE CALORIMETER.

A, Cask containing about 300 pounds of warm water.
B, Iron pipe and stop-cock.
C, Thermometer in warm-water pipe.
D, Rubber hose for warm water.
E, Calorimeter.
F, Platform scales weighing to ounces.
G, Thermometer, graduated to $\frac{1}{5}$ degree F.
H, Stand to support cask, A.

pound, and less than one-sixth of one per cent. on quantities of 11 to 12 pounds. The calorimeter was accurately leveled before making the experiments.

In testing the heat capacity of the calorimeter by this second method, the apparatus represented in Fig. 10 was used.

The calorimeter was brought to about the temperature of the room, in order to reduce to a minimum its changes of temperature by external influences; and after sufficient use of the agitator to bring the contained air to uniformity, readings of the central thermometer were taken once a minute during several minutes, in order to obtain the direction and rate of any change which might be observable. Meantime the cask A, of capacity considerably greater than that of the calorimeter (which is 200 lbs.), was filled with water by a hose, and warmed by steam, also by means of a hose, to 25° F. or more above the temperature of the room, only taking care to avoid a temperature so high as to cause rapid loss of heat by evaporation. After careful agitation with a stirring-stick, its temperature was taken, and a little drawn off, to waste, through the hose D (removed from the calorimeter), to bring the pipe and stop-cock B and the hose D to uniform temperature with the water. The stop-cock was then closed, and the end of the hose inserted in the upper end of the tubular shaft of the agitator, from which the thermometer and its case had been removed, as seen in Fig. 10; and the stop-cock was opened, and the water was allowed to flow from the cask into the calorimeter. Readings of the thermometer C were noted every 15 seconds during the filling, which takes 5 minutes. The temperature was pretty nearly uniform, and such variations as were observed, were due, it is probable, to imperfect mixing.

When the scales indicate that about the required quantity of water has flowed into the calorimeter, the stop-cock is closed, the hose is removed, the thermometer G, with its perforated tubular case, is replaced, the agitator is put in motion, and a set of readings of the thermometer G is taken at intervals of 1 minute (or less), for 5 minutes. The rate of cooling, which is regular, and very slow, being thus ascertained, it can be carried back to any desired point of time—in practice, to the time when the calorimeter was half full; and in a similar manner the slowly and regularly changing temperature can be brought forward to the same point of time. It is of course plain that the difference of these two temperatures at the same instant, will be the measure of the calorific capacity of the calorimeter.

It is necessary to compare the two thermometers, C and G, and to allow for any difference which may be found in their readings in identical circumstances. It was found that when both were immersed in water at 95° F. to the same extent as when used in these

determinations, the latter (G) read 0.3 deg. *lower* than the former (C). The observations follow.

TABLE VIII.

DETERMINATION OF THE HEAT CAPACITY OF CALORIMETER.

Time of readings by Auburndale horse-timer.		Readings of thermometer G when calorimeter is empty.	Readings of thermometer G after calorimeter is filled with water.	Readings of thermometer C in warm water while calorimeter is filling.
1		2	3	4
Min.	Sec.			
0	0	76.60°		
1	0	76.65°		
2	0	76.70°		
3	0	76.75°		
4	0	76.80°		
5	0	Began to fill calorimeter with warm water.		
6				101.6°
7				101.6°
7	30	76.975°	98.95°	
8				101.6°
9				101.6°
10		Filled.		101.6°
11				
12			98.725°	
13			98.675°	
14			98.625°	
15			98.575°	
16			98.525°	
17			98.500°	

By extending the range according to the ascertained rate of change of temperature, we obtain:

Change of empty calorimeter per minute, 0.05° during 3.5 minutes, 4 minutes to 7.5 minutes, and .05 × 3.5 = 0.175°, to add to 76.8°, making this temperature when half the water had entered the calorimeter, 76.975°.

Change of water after filling the calorimeter, 0.05° per minute during 4.5 minutes, to be carried back 4.5 minutes, from 12 minutes to 7.5 minutes, and .05 × 4.5 = 0.225°, to be added to 98.725°, making 98.950°.

Temperature of warm water before entering the calorimeter, 101.6°.

Weight of calorimeter and water, pounds	489.125
Weight of empty calorimeter, without thermometer and case	315.250
Weight of warm water put in	173.875

To the temperature ascertained by thermometer G, we must add 0.3°, by which amount it read lower than thermometer C, making:

$$76.975 + 0.3 = 77.275, \text{ and}$$
$$98.950 + 0.3 = 99.250.$$

Corrected for the varying specific heat of water, the corresponding number of British thermal units is set opposite each temperature, respectively, in the following table:

TABLE IX.

QUANTITIES OF HEAT IN BRITISH THERMAL UNITS.

	Degrees.	B. t. u.
Calorimeter, at half full	77.275	77.3056
Water, calorimeter half full	99.25	99.3278
Water before entering calorimeter	101.6	101.6848

Then:

$$x = \frac{(173.875 + 18.61) \times (101.6848 - 99.3278)}{101.6848 - 77.3056} =$$

$$\frac{129.485 \times 2.357}{24.3792} = 192.485 \times .09668 = 18.61.$$

The value of $x = 18.61$, the quantity sought, has to be found by a few trials, beginning with 17.19, found by the first method, which proves to be too small by 0.8 per cent. to satisfy the conditions of the equation.

Nine other similar determinations gave, with the foregoing, the ten following values: 18.09, 18.61, 18.50, 18.92, 19.06, 19.10, 19.20, 18.40, 18.55, 19.42.

The mean of all is	18.78
To this add for solder put on afterward, 2.09 lbs., sp. ht. = .048	.10
Calorific value of calorimeter as ascertained by the second method	18.88

This is nearly 10 per cent. more than was found by the first method, p. 719, which was 17.2.

By the third method:

At 5 hours 45 minutes P.M., when for an hour no steam had been drawn from the boiler, while steam pressure at about 51.6 pounds per square inch by a test guage had been steadily maintained, the steam must be considered as substantially "dry, satu-

rated steam." It could not be "superheated," because there was no superheating surface; and it could not contain much suspended water in liquid form, because there had been no ebullition for an hour, and the ebullition caused by drawing off to the calorimeter 45.4 cubic feet of steam—less than one-half the cubic contents of the steam space—through a $\frac{3}{4}$-inch pipe, must have been very slight.

Account of the experiment to determine by the third method the heat capacity of the calorimeter.

Height of mercurial barometer, inches	29.51
Atmospheric pressure; lbs. per sq. inch	14.494
Steam pressure by steam gauge	51.6
Steam pressure, absolute	66.094
Number of B. t. u. contained in one pound of steam of 66.094 lbs. per sq. inch pressure, absolute	1205.1060
Temperature to which water condensed from steam was reduced in the calorimeter	85.75°
Number of B. t. u. contained in water of temperature 85.75°	85.7965
Number of B. t. u. surrendered by each 1 lb. of steam on condensation and cooling to 85.75°, 1205.1060 − 85.7965 =	1119.3095
Quantity of water from condensed steam, drawn off and weighed on coin scales, lbs	7.238
Total number of B. t. u. given up by 7.238 pounds of steam; 1119.3095 × 7.238 =	8101.5622
Temperature of water in calorimeter before admitting steam, degrees F	48.45
Number of B. t. u. contained in each 1 lb. of this water	48.453
Number of B. t. u. gained by each 1 lb. of this water in rising from 48.45° to 85.75°, 85.7965 − 48.4530 =	37.3435
Total number of B. t. u. imparted to the water, divided by the number of B. t. u. gained by 1 lb., 8101.5622 ÷ 37.3435 =	216.9470
Weight of water in calorimeter	200.0000
Water value of calorimeter, lbs	16.9470

This result is only 1.47 per cent. less than the result obtained by the first method, and is strongly confirmatory of that result; especially in view of the fact that several experiments made in circumstances nearly similar, gave "saturated steam" when the value 17.2 was used for the calorimeter.

This third method is entitled to much weight, because it is precisely the method pursued in ordinary use. Yet it seems hardly probable that this value can be less than we have found it to be by direct calculation, by the first method (p. 719); and I have there-

fore adopted as the heat-equivalent of the calorimeter, in the following calorimetric work, in terms of water, 17.2 pounds.

The work done with this instrument, will be found in the sequel.

3. The Anemometer.—The germ, and perhaps something more than the germ, of this beautiful instrument, is to be found in Weisbach's *Lehrbuch der Ingenieur- und Maschinen-Mechanik*, Braunschweig, Friedrich Vieweg und Sohn, 1857, vol. 2, pp. 734, 735, under the name of the Wollaston Anemometer. In its present form, it is the joint production of Mr. F. H. Prentiss and the writer, although the principal share belongs to Mr. Prentiss.

Two glass tubes (Fig. 11), about 30 inches long, about 0.4 inch diameter inside and 0.7 inch outside, are connected at each end by means of stuffing-boxes, to suitable brass attachments, through which they are secured to a backing of wood.

Fig. 11.
Anemometer.

These attachments, at top and bottom, have each a tubular opening, with a stop-cock in the middle of its length, which can be turned at will to establish a free communication between the glass tubes, or to shut off all communication. Directly over each tube a brass drum-shaped vessel is placed, 4.25 inches in length and of equal diameter. The heads of these drums, at both ends, are formed of plate glass, properly secured with screw-rings, and made tight with suitable packing. A tubular opening extends up from each glass tube to the drum above it, and there is a hole in each drum, directly in line with the axis of the glass tube, each fitted with a stop-cock and a nipple for attaching a flexible pipe. Two sliding scales are arranged between the glass tubes, to measure, the one depressions, the other elevations of the surface of a liquid filling the lower half of the tubes, indicated in the cut, Fig. 11, near the middle of the height. Both stop-cocks are represented in the cut as closed.

The lower one being opened the two tubes, in communication at their lower ends, are filled up to about the middle of their height with a mixture of alcohol and water, care being taken to avoid wetting ior of the upper end of the tube poured through—the eing done through a small glass tube inserted through

the hole at the top of the drum, from which the stop-cock is removed for this purpose. The filling-tube is now to be raised so that its lower end is a little above the surface of the alcohol and water, the lower stop-cock is to be closed, and the upper one opened; and crude olive oil is to be carefully poured in until it fills the first tube up to the upper cross-tube into the second tube, and so finally fills both tubes and rises to about the middle of both drums.

The crude olive oil is of an olive-green color, and forms with the colorless alcohol and water a beautiful and very deep meniscus, if the tubes are clean, and the filling has been done with sufficient care, making the line of demarkation very distinct. Neither liquid discolors the glass, and if up-and-down motions are made cautiously and slowly, the liquids do not mix, and the common surfaces remain undisturbed. The specific gravity of the oil should be determined in advance, as it may vary a little, although we found it quite uniformly 0.916. The specific gravity of the alcohol and water may be made anything desired, between that of water, 1.000, and that of absolute alcohol, 0.813; but must always be made greater than that of the olive oil.

Where extreme delicacy is desired, the difference may be as small as 1 per cent.; that is, if the oil be as above, .916, the mixture of alcohol and water may be, .926. If the difference be much less than 1 per cent., the upper and lower liquids have a tendency to get into confusion, and do not constantly maintain a distinct line of demarkation at their common surface. For many purposes, a difference of specific gravity as great as 2 per cent. will give sufficient sensitiveness—fifty times as much range as a water column—and is more convenient to use.

The method of using this instrument to ascertain the force of chimney draft or other air current, is as follows: If both the stop-cocks between the tubes are opened, and both the small stop-cocks on the top of the drums are also opened, so that the surface of the oil in both drums alike is open to the air, *both* liquids will come to a level; the oil in the drums, very obviously, and the heavier mixture below the oil as certainly, if not quite as obviously; since if higher in one tube than in the other, the united weight of the two liquids in that tube must be greater than in the other, and must cause the liquid to sink down and flow into the other tube, raising the surface of the oil in the drum over that other tube, and causing it to flow across to the first tube, until both liquids are brought to a coincident height in the two tubes.

A slight difference will, however, commonly be found in the height of the lower liquid, owing to the unequal capillarity of the tubes, since these can rarely be obtained sufficiently near alike in caliber to avoid, when in equilibrium, a small, but sensible difference of level, which must be ascertained and allowed for.

If, now, the upper stop-cock between the tubes be closed, the lower one being left open, the surfaces of the two liquids will retain their respective heights in the two tubes, so long as the surface of the oil in the two drums remains subject to equal pressure. But if one drum be put in communication with a flue or chimney, by means of a flexible or other tube connected with the nipple of the small stop-cock—this stop-cock being open—while the other drum remains open to the air through its open stop-cock, the diminished pressure, due to chimney draft, upon the surface of the oil in that drum, will cause the oil to flow up into the drum, under the preponderating weight of the air on the surface of the oil in the other drum.

The surface of the oil in the drum is about 100 times as large as the inside cross-section of the glass tubes, and in the same proportion will the rise of the lower liquid on the one side, and its depression on the other, exceed the corresponding rise and depression of the upper surface of the oil.

If now, when equilibrium has been restored, the lower stop-cock be closed and the upper one opened, and the connection with the flue or chimney be severed—say by removing the flexible tube from the nipple—the lower liquid will be kept immovable, while the oil will flow through the upper cross-tube, and come to a common level in the two drums. On connecting the nipple again with the flue or chimney, and again closing the upper stop-cock and opening the lower one, a diminished repetition of the former action will take place; the lower liquid will rise a little in one tube and fall a little in the other, and the surface-level of the oil in the two drums will again become slightly unequal. This inequality, which will be much less than before, may be again removed by the same method; and a very few repetitions of this process will bring the difference in level of the surface of the lower liquid in the two tubes (corrected for inequality of capillary attraction, as explained above), to represent the entire difference in pressure on the surface of the oil in the two drums, due to the draft of the chimney; that is, a certain known height of column, filled, in one tube with a mixture of alcohol and water of specific gravity 0.926, with the flue-pressure resting on its surface, is just balanced by an equal

height filled with olive oil of specific gravity 0.916, with the pressure of the atmosphere resting on its surface. The differential column, therefore, represents a water column one-hundredth part as high, or a column of mercury $\frac{1}{1360}$ part as high. A draft which would be measured by 0.01 inch of mercury, or by 0.136 inch of water, would, on this anemometer, be measured by 13.5 inches of differential column. It is therefore a hundred times as sensitive as a water column, and more than 1,300 times as sensitive as a mercury column. If too sensitive, so that the required range would exceed the limits of the instrument, its sensitiveness can be reduced to any desired extent by a larger admixture of water, or by the use of pure water, as described by Weisbach, in which latter case the difference of specific gravity will be $(1.000 - 0.916) = 0.084$, and the sensitiveness 11.9 times as great as that of water alone, and 160 times as great as that of a mercury column.

This instrument with the respective specific gravities 0.937 and 0.916, difference, 0.21, equal to 2.1 per cent. was sensitive enough to show plainly the reduction of chimney draft caused by opening a sliding register in the fire-door for the admission of air above the fire, giving an aggregate open area of no more than six square inches. An instrument of such delicacy for determining pressures affords the best attainable data for estimating the velocity of air currents, far superior to the Casella revolving anemometer, or any other known to me. I will only add that after trying almost every applicable substance for packing the stuffing-boxes around the ends of the glass tubes, rings of cork, cut out of sheets of fine cork 0.25 inch thick, of suitable size to go tight over the tubes without bursting open, and to go easily into the stuffing-box, answered best; that is, they stopped all sensible leakage; but there was still a slow waste of alcohol—and perhaps of water also—by insensible leakage, and evaporation on coming to the air. The compression of the cork was very great; six rings of 0.25 inch each—1.5 inches in the aggregate—were compressed into a thickness of less than an eighth of an inch. Too much care cannot be taken to make all joints and stop-cocks tight. All passages through the brass should be drilled, and to this end, the turns at the lower end should be rectangular, instead of curved quarter-turns, as shown in Fig. 11.

4. The Incased Aneroid.—This is simply a fine aneroid barometer, 8.12 inches outside diameter, 2 inches in thickness, put into a brass case, resembling the case of a large steam gauge, fitted with a stout ring, by means of which a plate-glass cover is made air tight.

A 3-way cock at the bottom, connected by a flexible tube with a pipe inserted in a flue, affords facility for observing, alternately, and as often as desired, the difference between the barometric pressure of the external air, and the rarefied air within the brass case, outside of the aneroid, when the cock is open to the flue. Each inch of mercury is represented by an arc 2.21 inches in length, divided to tenths and fiftieths. Each of the smaller divisions is therefore equal to .044 inch, and to 1.12 millimeters, and is easily divisible by the practiced eye, to tenths, equal to .002 inch mercury, representing say 0.001 lb. pressure per square inch, and to .0277 inch of water. A hole 0.5 inch diameter, properly located in the back of the case, and stopped with an air-tight screw-plug, gives access, on removing the plug, to the adjusting screw of the aneroid, so that the latter can be compared—and if it need be adjusted—by the mercurial barometer. This instrument was found convenient and useful.

5. The Mercurial Barometer.—This was an ordinary "Signal Service" barometer, by J. & H. J. Green, New York, with freshly boiled mercury, and in all respects in good order. All observations were corrected for temperature, by attached thermometer. The floor of the boiler room is about 37 feet (11.28 meters), above mean tide in Boston harbor, and the barometer itself, as observed, 40 feet. This elevation is equal to 0.0456 inch of mercury and to 0.093 lb. per square inch. The mean weight of the atmosphere is therefore: $29.9218 - 0.0456 = 29.8762$ inches, and to $14.696 - 0.093 = 14.603$ lbs. per square inch. Lawrence is 26 miles N. by W. from Boston, in Lat. 42° 42′ 30″ N., Long. 71° 10′ 0″ W. The value of g (the force of gravity) is 32.163.

6. The Hygrometer.—This was the wet-and-dry bulb "Hygrophant," of J. S. F. Huddleston, Boston. The observations were reduced by Guyot's Tables, 3d edition, Smithsonian Institution, Washington, D. C.

7. Thermometers.—These were many in number, and in considerable variety; all which were used for purposes requiring accuracy being tested by Mr. J. S. F. Huddleston, Boston. All were graduated to the Fahrenheit scale, some to half degrees, some to one-fifth degree, and some to one-tenth degree. One long and delicate thermometer, sole survivor of its class, is described as follows:

Whole length	31.5 inches.
Length of bulb (mean)	2.3 "
Diameter throughout	0.25 "

Length of graduated stem..... 28 inches.
Graduated, range, 19° to 83° = 64°.
Graduated to $\frac{1}{10}$ degree.
Whole weight..... 1405 grains.
" glass, 80.5%..... 1132 "
" Hg, 19.5%..... 273 "
Sp. ht. glass, .1923; Hg, .0290, mean, .1705.
Heat value, $\frac{1405 \times .1705}{7000} = .034$ B. t. u.

This thermometer was used with the steam calorimeter, as were others similar to it, which were broken. Being accurately calibrated and carefully divided, .4375 inch to 1°, 0.437 = 1.11 millimeters to 0.1°, it may be read with much confidence to 0.01°. It is not to be supposed that actual temperatures, above 0° F. could be determined by it to this degree of accuracy; but differences of temperature, within a moderate range, as in calorimetric experiments, may be considered as correct within less than 0.01° at each reading, say 0.02° in the observed range. On a range of 10°, as in pyrometry, this would be 0.2%. On a range of 50°, as in calorimetry, 0.04%.

8. The Winckler Apparatus.—This clever and convenient instrument for ascertaining, approximately, the quantity of carbon dioxide (CO_2) in flue gases, by the volumetric method, will not be described, as it exists, so far as I know, in only one form, and is to be obtained from dealers in chemical instruments, apparatus and materials. It is not delicate enough to determine the quantity of carbon monoxide (CO), but will detect traces of it when present.

But this gas will *never* be found in more than very minute quantities in any reasonably well-managed fire, and for the convenient and expeditious determination of the CO_2, and consequently of the quantity of atmospheric air per pound of carbon (and per pound of coal, if the composition of the coal is known), the Winckler apparatus is very valuable. It was used in these experiments only as an auxiliary—the CO_2 and CO being ascertained throughout by the more accurate gravimetric method.

9. The Geissler Bulbs.—These are used in determining both the CO_2 and the CO in flue gases, by the gravimetric method, and are seen suspended from the scales, and also in place in the apparatus, in Fig. 17 (to be introduced in the sequel). I remark only that they should be of large size, in order to deal with considerable quantities of the absorbed gases.

10. The Chemical Balance.—This, also, should be of large size,

to weigh 200 milligrammes without injury to the scales; and of the best quality obtainable. The one used in these experiments, was made by H. Troemner, Philadelphia, weighing up to 200 grammes, = 3086.5 grains, or about 0.44 lb. av., divided to weigh to tenths of a milligramme, but capable, by skillful manipulation, of weighing to twentieths of a milligramme (.00005 gramme).

11. The Steam Gauge.—A 10-inch Bourdon steam gauge, made by the American Steam-Gauge Company, compared with a mercury column—as often before—both before and after the experiments, was put into a position where it could not be affected by heat from the boilers, and kept shut off except at the time of quarter-hourly readings. Every opening of the stop-cock, to let the pressure come to this gauge, produced an instantaneous lowering of the pressure in the small pipe leading from the boiler, and recorded itself by a slight mark on the trace of the Edson recording pressure gauge—a very satisfactory check upon the accuracy of the readings in point of time.

12. The Edson Pressure-Recording Gauge.—Continuous tracings from this instrument—night and day—were taken, and integrated, for comparison with the record of the test gauge.

A set of these tracings, for one week, will be found reproduced hereafter.

Some other minor pieces of apparatus will be briefly described, so far as necessary, in connection with the account of their use.

III.

It is proposed next to present a general summary of results, followed by a condensed record of the weekly experiments.

GENERAL SUMMARY OF RESULTS.

PACIFIC BOILER: Cold Blast, Natural Draft.
WARM-BLAST BOILER NO. 1: Abstractors with double tubes.
WARM-BLAST BOILER NO. 2: Abstractors with deflectors, applied to the "Pacific Boiler."

The results with anthracite, in the Pacific boiler, are the means for five weekly trials; all the others are for single weekly trials.

TABLE X.	Anthracite.	Bituminous.
Coal consumed, net, per week:		
Pacific Boiler	16264	12890
Warm Blast No. 1	20368	15184
Warm Blast No. 2	16740	
Water evaporated per week:		
Pacific Boiler	147039	121590
Warm Blast No. 1	180542	145075
Warm Blast No. 2	157483	
Pounds of water per pound of coal:		
Pacific Boiler	9.04	9.43
Warm Blast No. 1	8.86	9.55
Warm Blast No. 2	9.41	
Mean temperature of feed water:		
Pacific Boiler (Fahr.)	71.90°	72.40°
Warm Blast No. 1	38°	36°
Warm Blast No. 2	49°	
Mean temperature of external air, days:		
Pacific Boiler (Fahr.)	78.3°	71°
Warm Blast No. 1	34°	34.2°
Warm Blast No. 2	49°	
Steam gauge pressure above atmosphere, pounds per square inch:		
Pacific Boiler	47.54	47.30
Warm Blast No. 1	54.40	64.40
Warm Blast No. 2	42.50	
Mean barometric pressure, pounds per square inch:		
Pacific Boiler	14.47	14.61
Warm Blast No. 1	14.64	14.66
Warm Blast No. 2	14.70	
Steam pressure, absolute:		
Pacific Boiler	62.01	61.91
Warm Blast No. 1	69.04	79.06
Warm Blast No. 2	57.20	

TABLE X.	Anthracite.	Bituminous.
Pounds of water evaporated from and at 212° F., per pound of coal, days and nights:		
Pacific Boiler	10.51	10.58
Warm Blast No. 1	10.81	11.54
Warm Blast No. 2	11.12	
Water evaporated from and at 212° F. by day, per pound of coal burned during days and nights:		
Pacific Boiler	9.34	9.22
Warm Blast No. 1	10.00	10.72
Warm Blast No. 2	10.77	
Evaporative power of coal:		
Pacific Boiler	13.56	14.27
Warm Blast No. 1	13.45	14.30
Warm Blast No. 2	13.61	
Efficiency, days and nights, per cent.:		
Pacific Boiler	77.48	76.73
Warm Blast No. 1	80.37	80.70
Warm Blast No. 2	81.74	
Efficiency, days, per cent.		
Pacific Boiler	79.96	76.53
Warm Blast No. 1	87.05	84.21
Warm Blast No. 2	87.76	
Efficiency: water, days; coal, days and nights, per cent.:		
Pacific Boiler	68.87	64.61
Warm Blast No. 1	74.35	74.96
Warm Blast No. 2	79.20	
Losses: per cent., complement of efficiency: water, days only; coal, days and nights:		
Pacific Boiler	31.13	35.39
Warm Blast No. 1	25.65	25.04
Warm Blast No. 2	20.80	
Losses, per cent., at chimney, by radiation from brick-work, and by imperfect combustion, = CO:		
Pacific Boiler, chimney	17.75	17.03
Radiation	2.64	3.39
CO	2.13	2.85
	22.52	23.27
Warm Blast No. 1 chimney	15.00	14.24
Radiation	4.00	4.00
CO	0.63	1.06
	19.63	19.30
Warm Blast No. 2, chimney	12.83	
Radiation	4.00	
CO	1.43	
	18.26	

TABLE X.	Anthracite.	Bituminous.
Temperature of smoke-box, Fahr.:		
Pacific Boiler	368.3°	376.9°
Warm Blast No. 1	396.9°	397.4°
Warm Blast No. 2	377°	
Temperature of air supplied to furnace:		
Pacific Boiler	78.3°	71°
Warm Blast No. 1	337.7°	349.5°
Warm Blast No. 2	334°	
Temperature of escaping gases.		
Pacific Boiler	368.3°	376.9°
Warm Blast No. 1	189°	196°
Warm Blast No. 2	164°	
Gases cooled by abstractors:		
Pacific Boiler	0°	0°
Warm Blast No. 1	207.9°	201.4°
Warm Blast No. 2	213°	
Air warmed by abstractors:		
Pacific Boiler	0°	0°
Warm Blast No. 1	303.7°	315.5°
Warm Blast No. 2	285°	
Temperature of steam, days:		
Pacific Boiler	297.5°	297.3°
Warm Blast No. 1	361.1°	322.6°
Warm Blast No. 2	291.2°	
Difference of temperature, boiler and gases:		
Pacific Boiler, gases *above* boiler	70.8°	79.6°
Warm Blast No. 1, " *below* "	127.1°	126.6°
Warm Blast No. 2, " *below* "	127.2°	
Difference of temperature, boiler and air supply:		
Pacific Boiler, air *below* boiler	219.2°	226.3°
Warm Blast No. 1, " *above* "	21.6°	26.9°
Warm Blast No. 2, " *above* "	42.8°	
Pounds of flue gases per pound of coal, days:		
Pacific Boiler	22.39	25.23
Warm Blast No. 1	23.49	28.37
Warm Blast No. 2	24.17	
Pounds of water equivalent in heat capacity to flue gases per pound of coal; sp. heat of gases = 0.238.		
Pacific Boiler	5.33	6.00
Warm Blast No. 1	5.59	6.75
Warm Blast No. 2	5.75	
British thermal units carried off in gases per pound of coal, days:		
Pacific Boiler	1576	1835
Warm Blast No. 1	866	1092
Warm Blast No. 2	661	

TABLE X.	Anthracite.	Bituminous.
Efficiency *corrected* for difference in temperature of external air, and difference in time of banking fires:		
Pacific Boiler..... per cent.	68.87	64.61
Warm Blast No. 1.....	78.18	77.59
Warm Blast No. 2.....	81.43	
Difference of Efficiency: Points gained by warm blast, over Pacific Boiler, cold blast:		
Warm Blast No. 1.....	9.31	12 98
Warm Blast No. 2.....	12.56	
Ratio of gain to the larger quantity ($\frac{9.31}{78.18} = 11.9\%$ etc.)		
Warm Blast No. 1..... ...per cent.	11.9	16.7
Warm Blast No. 2	15.4	
Ratio of gain to the smaller quantity ($\frac{9.31}{68.87} = 13.5\%$ etc.):		
Warm Blast No. 1.....	13.5	20.1
Warm Blast No. 2.....	18.2	

The power consumed in driving the blower is about 1 per cent. of the whole power produced by the boiler in combination with a good steam engine.

It therefore appears that the net saving effected by the warm blast was from 10.7 to 15.5 per cent. of the fuel used with cold blast, which is the same thing as to say that discontinuing the warm blast would cause an increased consumption of fuel equal to from 12.3 to 18.9 per cent. of the quantity used with hot blast. Broadly stated, the gain is 10 to 15 per cent.

IV.

CONDENSED RECORD OF WEEKLY EXPERIMENTS.

The following tables are greatly condensed, embodying, as they do, the summing up of more than 1,250 pages of notes taken during the tests, and the results of very laborious calculations. Table XI., occupying eleven pages, is progressive, the successive sections,

nbered at the left hand 1 to 38, requiring for their full explana-
ı only preceding sections. Observe, that the line "Mean, for
hracite," gives for the Pacific Boiler (cold blast), the means of
first 5 weeks, A, B, C, D, E; and for the Warm-Blast Boiler,
means of the first and third week, G and I—the single weeks,
nd H, are to be compared with the corresponding means.

TABLE XI.—CONDENSED RECORD OF WEEKLY EXPERIMENTS.

KIND OF QUANTITY.	PACIFIC BOILER.			WARM-BLAST BOILER.		
	For the week		QUANTITIES.	For the week		QUANTITIES.
	1881.	ending,		1882.	ending,	
1. Pounds of coal thrown on the fire grate during the week: all anthracite except for weeks F & H, which are bituminous; and except 1326 pounds used in week I, for banking	A	July 16	16251.5	G	Feb. 4	21009
	B	" 23	16949	H	" 11	15842
	C	" 30	18652	I	May 20	Anthr. 15591
	D	Aug. 6	17951.5			Bitu. 1326
	E	" 13	15321			
	F	" 20	12836.5			
Mean, with anthracite			17025			18963
Mean of all			16326.9			17923
2. Pounds of dry wood burned during the week for kindling—Monday morning	A	July 16	271.5	G	Feb. 4	292
	B	" 23	261.5	H	" 11	280
	C	" 30	251.5	I	May 20	261
	D	Aug. 6	288.5			
	E	" 13	272			
	F	" 20	223			
Mean, with anthracite			269			276
Mean of all			261.8			278
3. Pounds of coal equivalent to wood burned during the week, being 0.4 of the wood burned	A	July 16	108.5	G	Feb. 4	116
	B	" 23	104.6	H	" 11	112
	C	" 30	100.5	I	May 20	104
	D	Aug. 6	115.4			
	E	" 13	109			
	F	" 20	89.2			
Mean, with anthracite			107.6			110
Mean of all			104.5			111

4. Pounds of ashes and residue accumulated during the week.....	A	July 16	2158	G	Feb. 4	3102
	B	" 23	2628	H	" 11	1539
	C	" 30	2809	I	May 20	1888
	D	Aug. 6	2432.5			
	E	" 13	2163.25			
	F	" 20	947			
Mean, from anthracite.....			2438.2			2495
Mean of all.....			2189.6			2176.8
5. Pounds of carbon in ashes and residue for the week.....	A	July 16	514	G	Feb. 4	617
	B	" 23	928	H	" 11	628
	C	" 30	923	I	May 20	287
	D	Aug. 6	572.8			
	E	" 13	631			
	F	" 20	29			
Mean, for anthracite.....			713.8			452
Mean of all.....			599.6			510.7
6. Pounds of coal equivalent to the carbon in ashes and residue for the week.....	A	July 16	623	G	Feb. 4	757
	B	" 23	1133	H	" 11	768
	C	" 30	1117.1	I	May 20	346
	D	Aug. 6	696.4			
	E	" 13	760			
	F	" 20	39			
Mean, for anthracite.....			865.3			551.5
Mean of all.....			727.6			623.7
7. Pounds of coal consumed during the week, allowing for wood consumed, and for coal equivalent to carbon in ashes and residue. Weeks F & H bituminous; all others anthracite.....	A	July 16	15737	G	Feb. 4	20368
	B	" 23	15921	H	" 11	15184
	C	" 30	17618.8	I	May 20	16740
	D	Aug. 6	17370.5			
	E	" 13	14670			
	F	" 20	12890			
Mean of anthracite.....			16263.5			18554
Mean of all.....			15701.2			17430.7

TABLE XI.—CONDENSED RECORD OF WEEKLY EXPERIMENTS.—*Continued.*

KIND OF QUANTITY.	PACIFIC BOILER.			WARM-BLAST BOILER.		
	For the week		QUANTITIES.	For the week		QUANTITIES.
	1881.	ending,		1882.	ending,	
8. Mean temperature of feed water during the week, degrees Fahrenheit	A	July 16	72.56°	G	Feb. 4	38°
	B	" 23	72.16°	H	" 11	36°
	C	" 30	71.40°	I	May 20	49°
	D	Aug. 6	71.28°			
	E	" 13	72.08°			
	F	" 20	72.40°			
Mean, with anthracite			71.90°			43.5°
Mean of all			71.98°			41
			Days. / Nights.			Days. / Nights.
9. Steam pressure by steam gauge; means for days and nights separately: days, left-hand column; nights, right-hand column	A	July 16	51.20 / 34.90	G	Feb. 4	54.4 /
	B	" 23	46.75 / 48.36	H	" 11	64.4 /
	C	" 30	47.65 / 55.34	I	May 20	42.5 /
	D	Aug. 6	51.18 / 53.76			/
	E	" 13	40.92 / 50.57			/ (Not recorded.)
	F	" 20	47.30 / 54.10			/
Mean, with anthracite			47.54 / 48.59			48.45 /
Mean of all			47.50 / 49.50			53.77 /
10. Pounds of water evaporated during the week while the dampers were open; days	A	July 16	124899	G	Feb. 4	167072
	B	" 23	126687	H	" 11	134976
	C	" 30	145234	I	May 20	152683
	D	Aug. 6	137922			
	E	" 13	119844			
	F	" 20	105605			
Mean, with anthracite			130917			159878
Mean of all			126699			151577

						13470
11. Pounds of water evaporated during the week while the dampers were closed; nights	A	July 16	15435	G	Feb. 4	10100
	B	" 23	18815	H	" 11	4800
	C	" 30	14673	I	May 20	
	D	Aug. 6	15361			
	E	" 13	16324			
	F	" 20	15984			
Mean, for anthracite			16122			9135
Mean of all			16099			9457
12. Total number of pounds of water evaporated during the entire week; days and nights	A	July 16	140334	G	Feb. 4	180542
	B	" 23	145502	H	" 11	145076
	C	" 30	159907	I	May 20	157483
	D	Aug. 6	153283			
	E	" 13	136167			
	F	" 20	121590			
Mean, for anthracite			147039			169013
Mean of all			142797			161034
13. Number of British thermal units apparently imparted to the water during the week, without correction for entrained water or superheating; days and nights	A	July 16	158 778 610	G	Feb. 4	212 652 655
	B	" 23	164 542 800	H	" 11	169 278 881
	C	" 30	181 224 054	I	May 20	181 676 279
	D	Aug. 6	173 745 190			
	E	" 13	154 147 537			
	F	" 20	137 580 746			
Mean, for anthracite			166 487 638			197 164 467
Mean of all			161 669 823			187 869 272
14. Number of British thermal units apparently imparted to the water during the week, while the damper was open, without correction for entrained water or superheating; days	A	July 16	141 377 751	G	Feb. 4	196 742 777
	B	" 23	143 231 922	H	" 11	157 362 369
	C	" 30	164 570 872	I	May 20	176 082 479
	D	Aug. 6	156 331 366			
	E	" 13	135 654 432			
	F	" 20	119 461 303			
Mean, for anthracite			148 233 269			186 412 628
Mean of all			143 437 941			176 729 208

TABLE XI.—CONDENSED RECORD OF WEEKLY EXPERIMENTS.—*Continued.*

KIND OF QUANTITY.	PACIFIC BOILER.				WARM-BLAST BOILER.			
	For the week		QUANTITIES.		For the week		QUANTITIES.	
	1881.	ending,			1882.	ending,		
22. Number of pounds of water that one pound of coal, by analysis, would evaporate from and at 212° F., if there were no loss of heat: weeks F & H bituminous, all the rest anthracite	A	July 16	13.55		G	Feb. 4	13.45	
	B	" 23	13.50		H	" 11	14.30	
	C	" 30	13.58		I	May 20	13.61	
	D	Aug. 6	13.55					
	E	" 13	13.64					
	F	" 20	14.27					
Mean, for anthracite			13.56				13.53	
Mean of all			13.68				13.79	
23. Ratio of heat utilized to the full heating power of the coal: per cent; days and nights; weeks F & H bituminous, all the rest anthracite.			Per cent.				Per cent.	
	A	July 16	76.38		G	Feb. 4	80.37	
	B	" 23	78.60		H	" 11	80.70	
	C	" 30	77.69		I	May 20	81.74	
	D	Aug. 6	75.72					
	E	" 13	79.03					
	F	" 20	76.73					
Mean, for anthracite			77.48				81.06	
Mean of all			77.36				80.94	
24. Ratio of heat utilized to the full heating power of the coal consumed, days and nights separately: weeks F & H bituminous; days, left-hand column; nights, right-hand column			Days.	Nights.			Days.	Nights.
	A	July 16	80.11		G	Feb. 4	87.05	43.05
	B	" 23	80.06	56.82	H	" 11	84.21	79.79
	C	" 30	80.03	54.99	I	May 20	87.76	75.80
	D	Aug. 6	79.85	55.71				
	E	" 13	79.74	57.48				
	F	" 20	76.53	73.60				
Mean, for anthracite			79.96	56.25			87.41	59.43
Mean of all			79.39	59.72			86.34	66.21

18. Total number of British thermal units imparted to the water during the entire week, corrected for entrained water and superheating; days and nights	A	July 16	157 308 281	G	Feb. 4	214 051 733
	B	" 23	163 053 188	H	" 11	170 185 214
	C	" 30	179 512 517	I	May 20	179 845 021
	D	Aug. 6	172 119 344			
	E	" 13	152 736 731			
	F	" 20	136 338 348			
Mean, for anthracite			164 946 012			196 948 377
Mean of all			160 178 068			188 027 323
19. Equiva'ent evaporation from and at 212° F.; pounds of water per pound of coal, corrected for ashes and residue, for wood, and for entrained water and superheating; days and nights	A	July 16	10.35	G	Feb. 4	10.81
	B	" 23	10.61	H	" 11	11.54
	C	" 30	10.55	I	May 20	11.12
	D	Aug. 6	10.26			
	E	" 13	10.78			
	F	" 20	10.95			
Mean, for anthracite			10.51			11.03
Mean of all			10.58			11.20
20. Equivalent evaporation from and at 212° F.: pounds of water per pound of coal burned; days and nights; days, left-hand column; nights, right-hand column			Days. / Nights.			Days. / Nights.
	A	July 16	10.85	G	Feb. 4	11.71 / 5.79
	B	" 23	10.80 / 7.67	H	" 11	12.04 / 11.41
	C	" 30	10.86 / 7.47	I	May 20	11.94 / 10.32
	D	Aug. 6	10.82 / 7 55			
	E	" 13	10.92 / 7.84			
	F	" 20	10.92 / 10.50			
Mean, for anthracite			10.85 / 7.63			11.83 / 8.06
Mean of all			10.86 / 8.21			11.90 / 9.17
21. Equivalent evaporation from and at 212° F.; days only, per pound of coal consumed days and nights. Weeks F & H are bituminous; all others anthracite. Pounds of water per pound of coal	A	July 16	9.21	G	Feb. 4	10.00
	B	" 23	9.22	H	" 11	10.72
	C	" 30	9.58	I	May 20	10.77
	D	Aug. 6	9.23			
	E	" 13	9.47			
	F	" 20	9.22			
Mean, for anthracite			9.34			10.39
Mean of all			9.32			10.50

TABLE XI.—CONDENSED RECORD OF WEEKLY EXPERIMENTS.—*Continued.*

KIND OF QUANTITY.	PACIFIC BOILER. For the week 1881.	ending,	QUANTITIES.		WARM-BLAST BOILER. For the week 1882.	ending,	QUANTITIES.	
22. Number of pounds of water that one pound of coal, by analysis, would evaporate from and at 212° F., if there were no loss of heat: weeks F & H bituminous, all the rest anthracite	A	July 16	13.55		G	Feb. 4	13.45	
	B	" 23	13.50		H	" 11	14.30	
	C	" 30	13.58		I	May 20	13.61	
	D	Aug. 6	13.55					
	E	" 13	13.64					
	F	" 20	14.27					
Mean, for anthracite			13.56				13.53	
Mean of all			13.68				13.79	
23. Ratio of heat utilized to the full heating power of the coal: per cent; days and nights; weeks F & H bituminous, all the rest anthracite.			Per cent.				Per cent.	
	A	July 16	76.38		G	Feb. 4	80.37	
	B	" 23	78.60		H	" 11	80.70	
	C	" 30	77.69		I	May 20	81.74	
	D	Aug. 6	75.72					
	E	" 13	79.03					
	F	" 20	76.73					
Mean, for anthracite			77.48				81.06	
Mean of all			77.36				80.94	
24. Ratio of heat utilized to the full heating power of the coal consumed, days and nights separately: weeks F & H bituminous; days, left-hand column; nights, right-hand column			Days.	Nights.			Days.	Nights.
	A	July 16	80.11		G	Feb. 4	87.05	43.05
	B	" 23	80.06	56.82	H	" 11	84.21	79.79
	C	" 30	80.03	54.99	I	May 20	87.76	75.80
	D	Aug. 6	79.85	55.71				
	E	" 13	79.74	57.48				
	F	" 20	76.53	73.60				
Mean, for anthracite			79.96	56.25			87.41	59.43
Mean of all			79.39	59.72			86.34	66.21

25. Ratio of heat utilized during days only, to the full heating power of the coal consumed during days and nights; steam, days only; coal, burned days and nights	A	July 16	Per cent. 67.97		G	Feb. 4	Per cent. 74.35	
	B	" 23	68.30		H	" 11	74.96	
	C	" 30	70.55		I	May 20	79.20	
	D	Aug. 6	68.12					
	E	" 13	69.43					
	F	" 20	64.61					
Mean, for anthracite			68.87				76.78	
Mean of all			68 16				76.17	
			Days.	Nights.			Days.	Nights.
26. Mean temperature of the smoke-box, deg. F., quarter-hourly observations; days, left-hand column; nights, right-hand column	A	July 16	384.9°		G	Feb. 4	396.9°	(Not recorded.)
	B	" 23	372.9°	250.0°	H	" 11	397.4°	
	C	" 30	371.1°	257.1°	I	May 20	377.0°	
	D	Aug. 6	364.8°	247.8°				
	E	" 13	348.0°	249.8°				
	F	" 20	376.9°	252.5°				
Mean, for anthracite			368.3°	251.0°			387.0°	
Mean of all			369.8°	251.4°			390.4°	
			Days.	Nights.			Days.	Nights.
27. Mean temperature of the boiler-room, deg. F., quarter-hourly observations; days, left-hand column; nights, right-hand column	A	July 16	85.2°		G	Feb. 4	68.7°	(Not recorded.)
	B	" 23	75.1°	72.1°	H	" 11	72.2°	
	C	" 30	76.0°	75.5°	I	May 20		
	D	Aug. 6	81.4°	79.6°				
	E	" 13	79.1°	75.6°				
	F	" 20	76.2°	73.3°				
Mean, for anthracite			79.4°	75.7°				
Mean of all			78.8°	75.2°				
			Days.	Nights.			Days.	Nights.
28. Mean temperature of external air, deg. F., quarter-hourly observations; days, left-hand column; nights, right-hand column	A	July 16	81.0°		G	Feb. 4	34.0°	(Not recorded.)
	B	" 23	76.1°	66.0°	H	" 11	34.2°	
	C	" 30	74.9°	67.7°	I	May 20	49.0°	
	D	Aug. 6	82.3°	76.8°				
	E	" 13	77.0°	73.1°				
	F	" 20	71.0°	64.9°				
Mean, for anthracite			78.3°	70.9°			41.5°	
Mean of all			77.1°	69.7°			39.1°	

TABLE XI.—CONDENSED RECORD OF WEEKLY EXPERIMENTS.—*Continued.*

KIND OF QUANTITY.	PACIFIC BOILER. For the week 1881.	ending,	QUANTITIES. Days.	Nights.	WARM-BLAST BOILER. For the week 1882.	ending,	QUANTITIES. Days.	Nights.
29. Number of pounds of air, by analysis of flue gases, per pound of coal consumed; days, left-hand column; nights, right-hand column..	A	July 16	20.04		G	Feb. 4	22.67	(Not ascertained.)
	B	" 23	21.26	34.63	H	" 11	27.55	
	C	" 30	18.92	33.80	I	May 20	23.34	
	D	Aug. 6	23.37	27.43				
	E	" 13	24.14	30.72				
	F	" 20	24.42	42.74				
Mean, for anthracite.....			21.55	31.65			23 00	
Mean of all.....			22.02	33.86			24.52	
30. Number of pounds of flue gases, by analysis, per pound of coal consumed; days, left-hand column; nights, right-hand column			Days.	Nights.				
	A	July 16	20.86		G	Feb. 4	23.49	
	B	" 23	22.08	35.45	H	" 11	28.37	
	C	" 30	19.74	34.62	I	May 20	24.17	
	D	Aug. 6	24.19	28.25				
	E	" 13	25.06	31.54				
	F	" 20	25.23	43.55				
Mean, for anthracite.....			22.39	32.46			23.83	
Mean of all.....			22.86	34.68			25.34	
31. Mean weekly barometric pressure, corrected; inches of mercury in left-hand column; pounds per square inch in right-hand column.			Inches Hg.	Lbs. per sq. in.			Inches Hg.	Lbs. per sq. in.
	A	July 16	29.438	14.41	G	Feb. 4	29.81	14.64
	B	" 23	29.492	14.48	H	" 11	29.86	14.66
	C	" 30	29.509	14.49	I	May 20	29.93	14.70
	D	Aug. 6	29.413	14.45				
	E	" 13	29.544	14.51				
	F	" 20	29.752	14.61				
Mean, for anthracite.....			29.479	14.47			29.87	14.67
Mean of all.....			29.525	14.49			29.87	14.67

			Days.	Nights.			Days.	Nights.
32. Mean ratio of heat lost at chimney to the full heating power of the coal; mean loss by radiation being deducted, per cent.; days, left hand column; nights, right-hand column	A	July 16	17.13	39.18	G	Feb. 4	8.95	52.95
	B	" 23	17.16	41.01	H	" 11	11.79	16.21
	C	" 30	17.34	40.29	I	May 20	8.24	20.20
	D	Aug. 6	17.45	38.52				
	E	" 13	20.66	22.40				
	F	" 20						
Mean, for anthracite			17.27	39.75			8.59	36.57
Mean of all			17.95	36.28			9.66	29.79
			Chimney.	Radiation.			Chimney.	Radiation.
33. Mean ratio of heat lost at chimney and by radiation, to the full heating power of the coal, per cent.; chimney, left-hand column; radiation, right-hand column	A	July 16			G	Feb. 4	15.63	4.00
	B	" 23	20.00	1.40	H	" 11	15.30	4.00
	C	" 30	19.21	3.10	I	May 20	14.26	4.00
	D	Aug. 6	19.53	4.75				
	E	" 13	19.58	1.39				
	F	" 20	19.27	3.39				
Mean, for anthracite			19.58	2.64			14.94	4.00
Mean of all			19.52	2.81			15.06	4.00
			Per cent.				Per cent.	
34. Mean ratio of sums of losses at chimney and by radiation, to the full heating power of the coal; complement of heat utilized (No. 23), per cent	A	July 16	22.66		G	Feb. 4	19.63	
	B	" 23	21.40		H	" 11	19.30	
	C	" 30	22.31		I	May 20	18.26	
	D	Aug. 6	24.28					
	E	" 13	20.97					
	F	" 20	23.27					
Mean, for anthracite			22.24				18 94	
Mean of all			22.32				19.06	
35. Number pounds of coal, corrected for wood and ashes, burned per week while the dampers were open; days	A	July 16	13352		G	Feb. 4	17522	
	B	" 23	13590		H	" 11	13612	
	C	" 30	15529		I	May 20	15112	
	D	Aug. 6	14806					
	E	" 13	12730					
	F	" 20	11210					
Mean, for anthracite			14001				16317	
Mean of all			13536				15415	

TABLE XI.—CONDENSED RECORD OF WEEKLY EXPERIMENTS.—*Continued.*

KIND OF QUANTITY.	PACIFIC BOILER.				WARM-BLAST BOILER.			
	For the week		QUANTITIES.		For the week		QUANTITIES.	
	1881.	ending,			1882.	ending,		
			Open.	Banked.			Open.	Banked.
36. Number of hours and minutes per week the dampers were open, left-hand column; number of hours and minutes per week the fires were banked, right-hand column.....	A	July 16	65:15	60:19	G	Feb. 4	48:57	75:48
	B	" 23	67: 1	59:26	H	" 11	52:36	70:21
	C	" 30	72:20	54:25	I	May 20	64:22	60:51
	D	Aug. 6	69:17	57:58				
	E	" 13	66:27	57:30				
	F	" 20	63:55	61:29				
Mean, for anthracite.....			68: 4	57:56			54:40	68:20
Mean of all.....			67:22	58:31			55:18	69: 0
37. Number of pounds burned per square foot of fire-grate area and per hour, weekly means.....	A	July 16	7.92		G	Feb. 4	12.99	
	B	" 23	7.85		H	" 11	9.89	
	C	" 30	8.31		I	May 20	9.09	
	D	Aug. 6	8.27					
	E	" 13	7.42					
	F	" 20	6.79					
Mean, for anthracite.....			7.95				11.04	
Mean of all.....			7.76				10.49	

The line "Mean of all," in each section, has not much significance, especially in sections relating to fuel, but may be found convenient in a general way.

Table XII. is the result of duplicate analyses, with repetitions in cases where the duplicate results appeared to be too discrepant. The anthracites were remarkably uniform, as, indeed, were the bituminous samples. The marked character of each kind of coal will be noticed.

In Table XIII. the hygrometric observations were reduced by Guyot's tables, each by itself, and a mean was taken of the results.

Tables XIV. and XV. are the result of continuous duplicate analyses of the flue gases, through each forenoon, each afternoon (except Saturday P.M.), and each night. Bottled samples were also taken simultaneously, for verification of results in cases of too great discrepancy between the two simultaneous duplicates.

Observe that, in the middle division of these tables, the sums of the figures in lines 1, 2, make the quantities in line 3, and that these correspond to the first line in the upper division; the sums of the figures in lines 4, 5, make the quantities in line 6, corresponding to line 2, upper division; the sums of the figures in lines 7, 8, make the quantities in line 9, corresponding to the third line in the upper division; and that the sums of the figures in lines 2, 5, 9, 10, make the quantities in line 11. Finally, the figures in wide-face type, lines 3, 6, 9, 12, make 100.00.

In the lower division, the figures in lines 1, 2, those in lines 4, 5, and those in lines 6, 7, added together, make in each case 100.00. The quantities, or ratios, in line 8, are simply 100 times the quotient of the numbers in line 7, divided by those in line 6.

In line 10, the O combined with hydrogen in the coal, disappears in desiccating the gases, and does not appear in the dry gases.

All necessary details concerning the manner of arriving at the several values inserted in these tables, will be found in the sequel.

TABLE XII.—CONDENSED RECORD OF WEEKLY EXPERIMENTS.

ANALYSES OF COALS FOR THE WEEKS DESIGNATED,		PACIFIC BOILER.							WARM-BLAST BOILER.			
		A	B	C	D	E	F	1881. Anthracite. Mean.	G	H	I	1882. Anthracite. Mean.
Ending,		July 16.	July 23.	July 30.	Aug. 6.	Aug. 13.	Aug. 20.		Feb. 4.	Feb. 11,	May 20.	
Hydrogen	H,	1.84	1.87	1.85	1.87	1.85	3.84	1.86	1.89	3.79	1.80	1.84
Carbon	C,	82.41	81.90	82.64	82.24	82.96	81.03	82.43	81.51	81.71	82.92	82.22
Water	H_2O,	3.40	3.25	2.37	2.55	2.32	0.63	2.78	2.49	1.02	2.39	2.44
Ash		10.12	10.03	10.11	10.36	9.99	7.19	10.12	11.83	5.75	9.76	10.80
Sulphur	S,						0.82			0.82		
Oxygen	O,	2.23	2.95	3.03	2.98	2.88	4.49	2.81	2.28	4.91	3.13	2.70
Nitrogen	N,						2.00			2.00		
		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

NOTE.—S O and N are not separately determined in anthracite.

TABLE XIII.—ATMOSPHERIC AIR.

							Mean.				Mean.
Grains per cubic foot, O and N	491.4	494.6	499.0	484.0	497.8	506.3	495.5	565.0	553.0		559.0
Grains per cubic foot, Water	6.5	5.7	6.6	7.6	5.7	5.5	6.3	2.09	2.00		2.04
Ratio of water to air; per cent	1.28	1.15	1.30	1.54	1.15	1.07	1.25	0.37	0.36		0.37

TABLE XIV.—CONDENSED RECORD OF WEEKLY EXPERIMENTS.

ANALYSES OF DRY FLUE GASES WHILE THE DAMPERS WERE OPEN; FOR THE WEEKS DESIGNATED.		PACIFIC BOILER.							WARM-BLAST BOILER.			
		A	B	C	D	E	F	1881. Anthracite,	G	H	I	1882. Anthracite,
Days,	Ending,	July 16.	July 23.	July 30.	Aug. 6.	Aug. 13.	Aug. 20.	Mean.	Feb. 4.	Feb. 11.	May 20.	Mean.
1. Carbon dioxide	CO_2,	14.00	13.19	14.38	12.13	11.82	11.22	13.10	12.61	10.39	12.27	12.44
2. Carbon monoxide	CO,	.30	.25	.51	.20	.22	.56	.30	.08	.12	.18	.13
3. Oxygen uncombined	O,	11.20	11.89	10.73	12.81	13.06	12.96	11.94	12.45	13.89	12.73	12.59
4. Nitrogen	N,	74.50	74.67	74.38	74.86	74.90	75.46	74.66	74.86	75.60	74.82	74.84
Total		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1. Carbon combined in CO_2	C,	3.82	3.60	3.92	3.31	3.22	3.06	3.57	3.44	2.83	3.35	3.40
2. Oxygen combined in CO_2	O,	10.18	9.59	10.46	8.82	8.60	8.16	9.53	9.17	7.56	8.92	9.04
3. Carbon dioxide	CO_2,	**14.00**	**13.19**	**14.38**	**12.13**	**11.82**	**11.22**	**13.10**	**12.61**	**10.39**	**12.27**	**12.44**
4. Carbon combined in CO	C,	.13	.11	.22	.09	.10	.15	.13	.03	.05	.08	.06
5. Oxygen combined in CO	O,	.17	.14	.29	.11	.12	.21	.17	.05	.07	.10	.07
6. Carbon monoxide	CO,	**.30**	**.25**	**.51**	**.20**	**.22**	**.36**	**.30**	**.08**	**.12**	**.18**	**.13**
7. O free, but required by CO	O,	.18	.14	.29	.12	.13	.20	.17	.05	.07	.10	.08
8. Oxygen surplus	O,	11.02	11.75	10.44	12.69	12.93	12.76	11.76	12.40	13.82	12.62	12.51
9. Oxygen uncombined	O,	**11.20**	**11.89**	**10.73**	**12.81**	**13.06**	**12.96**	**11.93**	**12.45**	**13.89**	**12.73**	**12.59**
10. O combined with hydrogen	O,	.70	.68	.74	.62	.59	1.22	.67	.69	1.07	.59	.64
11. O total, combined and free	O,	22.43	22.30	22.22	22.36	22.37	22.54	22.30	22.35	22.58	22.37	22.36
12. Nitrogen = (77 ÷ 23) O	N,	**74.50**	**74.67**	**74.38**	**74.86**	**74.90**	**75.46**	**74.66**	**74.86**	**75.60**	**74.82**	**74.84**
Total		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100 00	100.00	100.00
1. Proportion of C in the CO_2	%	96.71	97.04	94.69	97.35	96.99	95.33	96.56	99.14	98.22	97.67	98.40
2. Proportion of C in the CO	%	3.29	2.96	5.31	2.65	3.01	4.67	3.44	.86	1.78	2.33	1.60
3. Loss of heat by CO	%	2.07	1.83	3.36	1.60	1.81	2.85	2.13	0.63	1.06	1.43	1.03
4. Proportion of O combined	%	49.66	46.68	51.71	42.71	41.62	42.50	46.48	44.30	38.53	43.00	43.65
5. Proportion of O free	%	50.34	53.32	48.29	57.29	58.38	57.50	53.52	55.70	61.47	57.00	56.35
6. Proportion of O required	%	50.47	47.31	53.02	43.25	42.20	43.43	47.25	44.52	38.81	43.45	43.98
7. Proportion of O surplus	%	49.53	52.69	46.98	56.75	57.80	56.57	52.75	55.48	61.19	56.55	56.02
8. Ratio of O surpl's to O req'd	%	98.13	111.38	88.62	131.23	136.97	130.24	113.27	124.61	158.46	130.14	127.36

TABLE XV.—CONDENSED RECORD OF WEEKLY EXPERIMENTS.

ANALYSES OF DRY FLUE GASES WHILE THE DAMPERS WERE CLOSED; FOR THE WEEKS DESIGNATED.		PACIFIC BOILER.							WARM-BLAST BOILER.			
Nights,	Ending,	A	B	C	D	E	F	1881. Anthracite, Mean.	G	H	I	1882. Anthracite, Mean.
		July 16.	July 23.	July 30.	Aug. 6.	Aug. 13.	Aug. 20.		Feb. 4.	Feb. 11.	May 20.	
1. Carbon dioxide	CO_2,	(Not recorded.)	5.09	4.99	5.69	5.62	6.23	5.35	(Not recorded.)	(Not recorded.)	(Not recorded.)	
2. Carbon monoxide	CO,		2.15	2.38	3.18	2.57	.37	2.57				
3. Oxygen uncombined	O,		17.21	17.21	16.06	16.48	17.29	16.74				
4. Nitrogen	N,		75.55	75.42	75.07	75.33	76.11	75.34				
Total.....			100.00	100.00	100.00	100.00	100.00	100.00				
1. Carbon combined in CO_2..	C,		1.39	1.36	1.55	1.53	1.70	1.46				
2. Oxygen combined in CO_2 .	O,		3.70	3.63	4.14	4.09	4.53	3.89				
3. Carbon dioxide	CO_2,		**5.09**	**4.99**	**5.69**	**5.62**	**6.23**	**5.35**				
4. Carbon combined in CO ..	C,		.92	1.02	1.36	1.10	.16	1.10				
5. Oxygen combined in CO..	O,		1.23	1.36	1.82	1.47	.21	1.47				
6. Carbon monoxide	CO,		**2.15**	**2.38**	**3.18**	**2.57**	**.37**	**2.57**				
7. O free, but required by CO.	O,		1.23	1.36	1.82	1.47	.21	1.47				
8. Oxygen surplus.....	O,		15.98	15.85	14.24	15.01	17.08	15.27				
9. Oxygen uncombined	O,		**17.21**	**17.21**	**16.06**	**16.48**	**17.29**	**16.74**				
10. O combined with hydrogen	O,		.42	.34	.40	.47	.70	.41				
11. O total, combined and free.	O,		22.57	22.53	22.42	22.50	22.73	22.50				
12. Nitrogen (77 ÷ 23) O	N,		**75.55**	**75.42**	**75.07**	**75.33**	**76.11**	**75.34**				
Total.....			100.00	100.00	100.00	100.00	100.00	100.00				
1. Proportion of C in CO_2 ...	%		60.17	57.16	53.24	58.19	91.46	57.19				
2. Proportion of C in CO....	%		39.83	42.84	46.76	41.81	8.54	42.81				
3. Loss of heat by CO.	%		25.37	27.27	29.68	26.50	5.07	27.20				
4. Proportion of O combined.	%		23.72	23.61	28.35	26.78	23.93	25.61				
5. Proportion of O free	%		76.28	76.39	71.65	73.22	76.07	74.39				
6. Proportion of O required .	%		29.17	29.67	36.46	33.29	24.86	32.15				
7. Proportion of O surplus ..	%		70.83	70.33	63.54	66.71	75.14	67.85				
8. Ratio of O surpl's to O req'd	%		241.34	237.28	174.28	200.40	302.30	213.32				

PYROMETRIC MEASUREMENTS OF TEMPERATURES.—All temperatures ascertained by the use of the water-platinum pyrometer, heretofore described, are embodied in the following tables, and these tables, in turn, are graphically represented in the accompanying diagrams. Temperatures were taken at both boilers, but the greater number, probably, at Warm-Blast Boiler No. 1, since special provision was made in the setting of that boiler for convenient use of the pyrometer. The high temperatures in Table XVI. were taken at Warm-Blast Boiler No. 2 (which was "Pacific Boiler" remodeled to warm blast), more than two months after the close of the last weekly experiment, ending May 20, 1882. My assistants went to Lawrence on a morning train, took matters just as they found them in the regular daily use of the boiler, and obtained the results in this table—partly melting the platinum balls in experiment 6—probably the result of some slight impurity in the platinum. I have used, for the most part, the temperatures obtained by the first (and simplest) method of reducing the pyrometric observations to degrees F., partly because that method gives a result a little too high, in most cases—not more than 1 per cent. too high—and we are sure that the heat-carrier can never be hotter than the flame or other source of heat to be measured, and may be a little cooler.

TABLE XVI.

PYROMETRIC OBSERVATIONS OF TEMPERATURES AT WARM-BLAST BOILER NO. 2, JULY 28, 1882. OBSERVATIONS NOS. 1, 2, 3 AND 4, AT BRIDGE WALL. NOS. 5 AND 6 IN THE HEART OF THE FIRE.

NO. OF OBS.	Temperature of water in pyrometer, 2.1053 lbs.	Number of British thermal units in water above 0° F.	HEAT-CARRIER.		Observed loss of temperature by heat-carrier at assumed ratio of sp. ht. for Pt, 30 to 1, for Fe. 6 to 1. See Table VI.	True loss of temperature and true temperature of heat-carrier when taken from the fire.
			Kind of Metal.	Ratio of water to heat carrier.		
1	2	3	4	5	6	7
1	96.65 81.20	96.71995 81.23740	Pt.	105.265	1629.8	1488.3 96.7
	15.45	15.48255				1585.0
2	99.3 83.4	99.3779 84.4418	Pt.	105.265	1677.5	1526.9 99.3
	15.9	15.9361				1626 2
3	102.51 85.40	102.59753 85.44580	Pt & Fe.	105.265	1805.5	1496.8 102.5
	17.11	17.15173				1599.3
4	103.02 86.16	103.10906 86.20732	Pt & Fe.	105.265	1779.16	1483.1 103.0
	16.86	16.90174				1586.1
5	110.30 81.54	110.41090 81.57808	Pt.	105.265	3035.1	2546.0 110.3
	28.76	28 83282				2356.3
6	113. 81.	113.121 81.037	Pt.	107.7	3455.4	2835.2 113.0
	32.	32.084				2948.2

$$\text{Mean of 1 and 2} = \frac{1585.0 + 1626.2}{2} = 1605.6.$$

$$\text{Mean of 3 and 4} = \frac{1599.3 + 1586.1}{2} = 1592.7.$$

$$\text{Mean of 1, 2, 3, 4} = \frac{1605.6 + 1592.7}{2} = 1599.15.$$

$$\text{Mean of 5 and 6} = \frac{2656.3 + 2948.2}{2} = 2802.25.$$

About one-sixth of the platinum was fused in observation 6, and cooled in drops, like shot; and one drop adhered to the lip of the pyrometer, and did not enter the water at all—a circumstance which raised the "ratio" to 107.7.

TABLE XVII.

TEMPERATURES DEDUCED FROM PYROMETRIC OBSERVATIONS IN TABLE XVI., BY THE SECOND AND THIRD METHODS, AS DESCRIBED ON p. 45. THE THIRD METHOD IS A LITTLE THE MOST ACCURATE.

	SECOND METHOD.		THIRD METHOD.				
NO. OF OBS.	Observed loss, plus final temperature of heat-carrier.	True temperatures by second method, deg. Fahr.	Final temperatures minus 32° F. in deg. F.	Ratio pyr. to Fahr. deg.	Final temp. minus 32° F., reduced to pyrometer deg.	Observed loss, plus final t. above 32° in pyrometer deg.	True temperatures by third method, deg. Fahr.
1	2	3	4	5	6	7	8
1	1629.80		96.65			1629.80	1538.9
	96.65		32.			62.65	32.0
	1726.45	1566.3	64.65 × .969 = 62.65			1692.45	1570.9
2	1677.50		99.3			1677.50	1579.3
	99.30		32.			65.21	32.0
	1776.80	1606.7	67.3 × .969 = 65.21			1742.71	1611.3
3	1805.50		102.51			1805.50	1530.1
	103.51		32.			68.32	32.0
	1908.01	1546.6	70.51 × .969 = 68.32			1873.82	1562.1
4	1779.60		103.02			1779.16	1517.6
	103.02		32.			68.82	32.0
	1882.62	1534.1	71.02 × .969 = 68.82			1847.98	1549.6
5	3035.10		110.30			3035.10	2599.1
	110.30		32.			75.87	32.0
	3145.40	2623.0	78.30 × .969 = 75.87			3110.97	2631.1
6	3455.40		113.0			3455.40	2888.1
	113.00		32.0			78.49	32.
	3568.40	2911.3	81.0 × .969 = 78.49			3533.89	2920.1

The "true temperatures," in columns 3 and 8, are found by the use of Table VI. (except Nos. 5 and 6, which go too high for Table VI., and are obtained from Table IV.), in the manner explained on p. 36. Observe that in Nos. 1, 2, 4 and 6, the platinum heat-carrier was used; and Nos. 3 and 4, the compound, Pt, Fe, heat-carrier. The three methods do not give results very discrepant. The first method gives temperatures a little too high; the second a little too low; the third, usually a little nearer correct. The greatest differences occur with the Pt, Fe heat-carrier.

TABLE XVIII.

TEMPERATURES AT BRIDGE WALL, ASCERTAINED BY THE USE OF THE WATER-PLATINUM PYROMETER. DEGREES FAHRENHEIT.

DATE 1881.	TIME. h.	m.		Temperature, deg. F.	DATE 1881.	TIME h.	m.		Temperature, deg. F.	DATE 1881.	TIME. h.	m.		Temperature, deg. F.
July					July					July				
8	10	30	A.M.	787	11	11	30	A.M.	1431	14	4	40	P.M.	1445
	10	30		808		12	31	P.M.	1536		4	50		1419
	11	40		1097		12	31		1427		5			1279
	11	40		1153	12	4	35		1363		5	10		1332
9	9	50		1095		4	45		1381		5	20		1262
	9	50		991		4	55		1251		5	20		1056
	11			735		5	15		1249	15	11	35	A.M.	993
	11			770		5	30		1185		11	50		883
	11	11		985	13	3	20		1339		12	5	P.M.	915
	11	11		953		3	30		1266		3	40		1327
	11	11		1018		3	40		1322		4			1258
	11	11		1045		3	50		1377		4	15		1017
	12		M.	1112		3	55		1236		4	25		728
	12			1129		4	7		1222		4	40		799
	12			1023		4	15		1186		5			894
	12			1105		4	25		1154		5	25		862
	1	45	P.M.	1342	14	9	20	A.M.	1056		5	45		741
	1	45		1345		9	30		1056		5	45		653
	1	45		1322		9	40		1026	18	10	5	A.M.	1216
	1	45		1296		9	50		1205		10	25		1406
	4			1386		10			1259		10	45		1376
	4			1382		10	10		1172		11	15		1296
	4			1324		10	20		1208		11	50		1474
	4			1305		11	20		1472	19	1	25	A.M.	*526
	4	55		894		11	35		1239		1	25		535
	4	55		974		11	45		1320		10	20		1260
	5	55		1024		11	55		1329		11	5		1381
	5	55		1050		12	5	P.M.	1418		11	20		1305
*	8	30	A.M.	1431		12	15		1259		11	35		1222
*	8	30		1310		2	25		1438	21	12	30	A.M.	*653
*	8	30		1303		3	45		1447		12	30		*674
*	8	30		1366		3	55		*1611	22	12	30	A.M.	*537
11	10	30		1409		4	5		1404		12	30		*556
	10	30		1479		4	20		1289	23	1	30	A.M.	*537
	11	30		1557		4	30		1318		1	30		*556

* Date not recorded. * Perhaps 100° too high. * Fires banked.

This table is represented graphically, as a profile in Fig. 12, the temperatures being represented as ordinates at equal distances, but in the same order as in this table. The temperatures for July 14 are represented graphically in Fig. 13, with the ordinates properly spaced to represent the respective times at which they were taken.

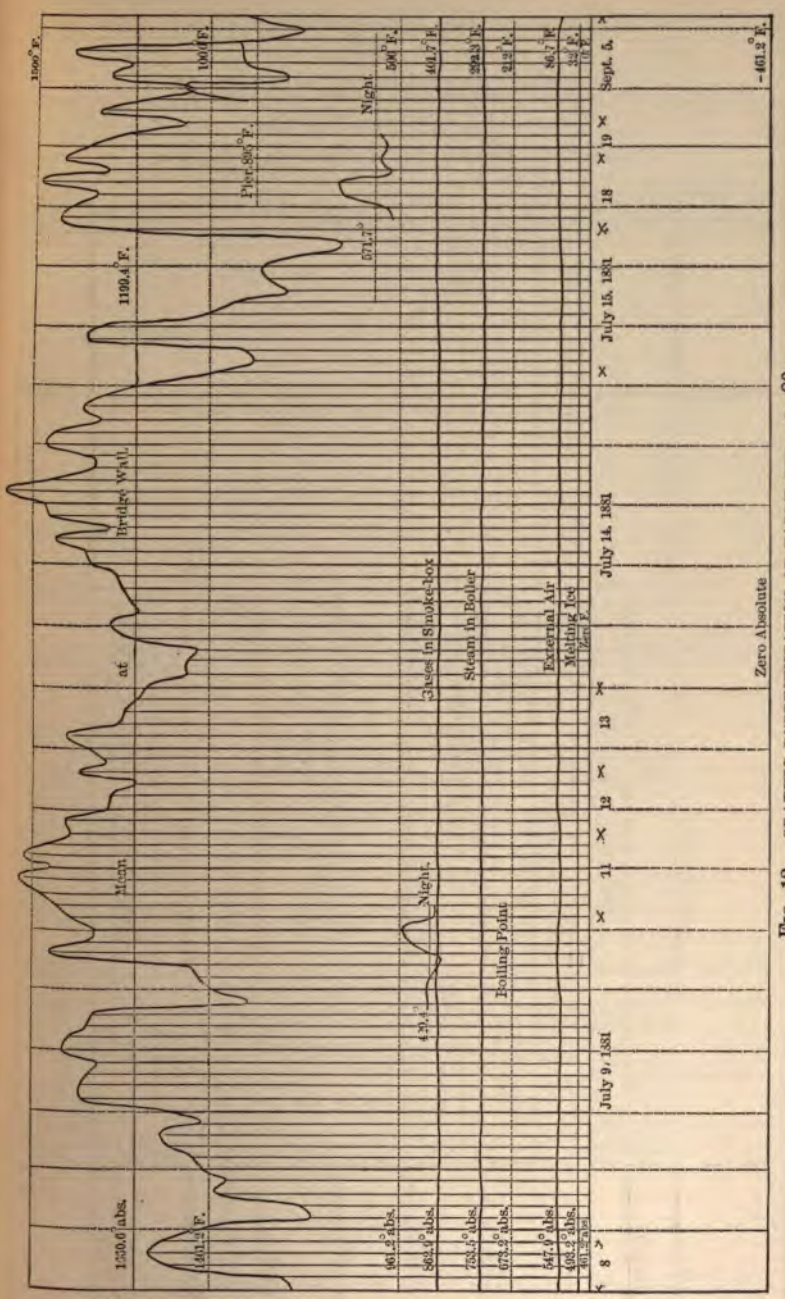

FIG. 12.—GRAPHIC REPRESENTATION OF TABLE XIX., P. 80.

Fig. 13.

GRAPHICAL REPRESENTATION OF PART OF TABLE XIX.

PACIFIC BOILER: JULY 14. 1881.

SCALES: HORIZONTAL ⅝ IN.=1 HOUR: VERTICAL 500°=1 INCH.

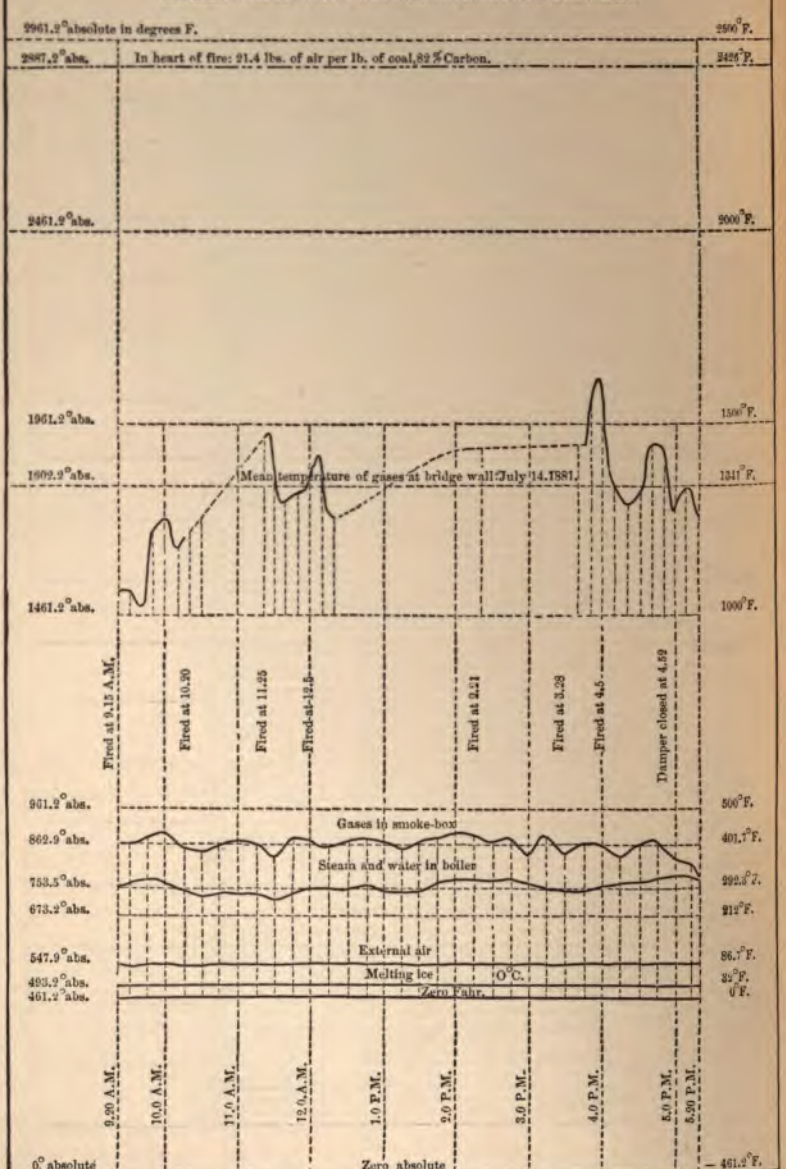

TABLE XIX.

PYROMETRIC MEASUREMENTS OF TEMPERATURE IN ARCH OVER WARM-BLAST BOILER NO. 1; FEBRUARY 13, 1882.

TIME. h. m. Part of Day.	TEMPERATURE OF WATER. At immersion of heat-carrier.	TEMPERATURE OF WATER. After cooling of heat-carrier.	INCREASE OF HEAT. In degrees F.	INCREASE OF HEAT. In British thermal units.	HEAT-CARRIER. Kind of metal.	HEAT-CARRIER. Ratio assumed of water to heat-carrier.	RESULTING TEMPERATURES. Lost by heat carrier in cooling.	RESULTING TEMPERATURES. Temperatures sought in degrees Fahr.
1	2	3	4	5	6	7	8	9
8:22 A.M.	71.3	77.7	6.4	6.4098	Pt.	100	630.2	707.9
8:45	77.6	83.8	6.2	6.2114	Pt.	100	611.8	695.6
2: 0 P.M.	77.22	83.17	5.95	5.9609	Pt.	100	588.4	671.6
2:34	82.8	87.8	5.0	5.0100	Pt.	100	498.8	586.6
3: 3	86.9	93.6	6.7	6.7134	Pt.	100	658.4	752.0
3:33	92.6	99.4	6.8	6.8180	Pt.	100	668.1	767.5
4:27	80.6	89.0	8.4	8.4164	Pt.	100	811.2	903.2

The highest observed temperature of superheated steam in the boiler, was 344° F., and the highest temperature of the iron must have been about midway, say, $\frac{344° + 903°}{2} = 624°$, or perhaps a little higher

TABLE XX.

COMPARISON OF TEMPERATURES FOUND WITH PACIFIC AND WARM-BLAST BOILERS.

LOCATION OF TEMPERATURES.	TEMPERATURES: DEGREES FAHR. Pacific Boiler.	Warm-Blast Boiler.	Difference.
In heart of fire	2426°	2796°	370°
At bridge wall	1341°	1599°	258°
At pier		895°	
In smoke-box	368°	377°	9°
Air admitted to furnace	78°	334°	256°
Steam and water in boiler	292°	300°	8°
Gases escaping to chimney	368°	164°	204°
External air	78°	34°	44°
Gases cooled, Warm-Blast Boiler			213°
Air warmed, Warm-Blast Boiler			300°

Before any just or useful comparison can be instituted between the several figures in Table XX. it will be necessary, or at least convenient, to reduce them all to a common basis—1° temperature

of external air. This will affect many of the other figures. For simplicity and convenience, we will reduce this, in both cases, to 0° C., = 32° F., which will reduce the temperature in the case of the Pacific Boiler, 78° − 32° = 46°, and in the case of the Warm-Blast Boiler, 34° − 32° = 2° F. A corresponding reduction would result in the temperature of the fire; but here another equalization is required.

The temperature of the heart of the fire is affected chiefly by two causes, namely: *First*, the quantity of air passing through the fire per pound of coal burned; and, *second*, the temperature of this air. For the latter, we merely subtract, as above mentioned, 46° from the temperature in the case of the Pacific Boiler, and 2426° − 46° = 2380°; and in the case of the Warm-Blast Boiler, 2796° − 2° = 2794°.

But these temperatures were found in different quantities of air: 21.28 pounds of air per pound of coal, in the former case, and in the latter, 20.36 pounds. Taking this last quantity in both cases, and assuming the anthracite coal to be in such a state of ignition that the hydrogen it may have contained has all been consumed, and neglecting the moisture in the air, we have, 0.238 being the specific heat of air, and also the gases of combustion; 0.82 the proportion of carbon in the coal, and 14,544 B. t. u. the full heating power of 1 pound of carbon:

$$\frac{14544 \times 0.82}{20.36 \times .238} = \frac{11926.08}{4.84568} = 2461$$

This will be the increment of heat, in degrees F., in passing through the fire in both cases; to be added in the one case to 32°, and in the other case to 332°, the difference, 300°, being due to heat derived, in the abstractor, from the outflowing gases, in the Warm-Blast Boiler. Then:

Pacific Boiler	2461° + 32° = 2493°
Warm-Blast Boiler.....	2461° + 332° = 2793°
Difference.....	2793° − 2493° = 300°

There will be less difference at the bridge wall, as the temperature tends to equalize itself with that of the boiler, and this tendency is the more rapid the greater the difference between the fire and hot gases on the one hand, and the boiler and its contents on the other. I arrive at the following mean temperatures, under equal conditions:

AT THE BRIDGE WALL.

Pacific Boiler	1340° F.
Warm-Blast Boiler	1600° F.
Difference, 1600° − 1340° =	260° F

The temperature at the pier, we found 895° (Fig. 12), and the corresponding temperature for the warm blast is 1050°. We then have:

FLUE GASES:

At the pier, about to enter flues,

Warm-Blast Boiler	1050° F.
Pacific Boiler	895° F.
Difference, 1050° − 895° =	155° F.

Discharged to chimney,

Pacific Boiler	373° F.
Warm-Blast Boiler	162° F.
Difference, 373° − 162° =	221° F.

The temperature at the smoke-box will depend chiefly on that of the steam and water in the boiler; and that, in turn, depends in great measure on the rapidity with which steam is drawn off. We will assume the temperature of the steam to be 300° F., which is not very far from the mean, corresponding to 67.2 pounds pressure per square inch, absolute, and to about 52.5 pounds steam-gauge pressure. (The mean, for the Pacific Boiler, was 47.50, and for the Warm-Blast Boiler, 53.77.) The corresponding temperature in smoke-box, we have found to be 377° for external air at 34° (Table XX.), and for 32° we may properly call it 375° F. We have found the temperature in smoke-box, Pacific Boiler, to be 368° with 47.5 lbs. the square inch mean steam pressure, corresponding to a temperature of 285° in the boiler. Adding 5°, to bring it up to our assumed temperature, 300°, we have 368° + 5° = 373° F.; that of the Warm-Blast Boiler being, as we have seen, 375° F. The gases discharged from the Warm-Blast Boiler to the chimney, we have found to be at 164°, with external air at 34°, and we may call them, for air at 32°, 162° F.

We may now reconstruct our table, on a basis of equal temperature of external air, and throw its numbers into the form of a diagram, fairly representing the comparative temperatures in the two boilers (Fig. 14).

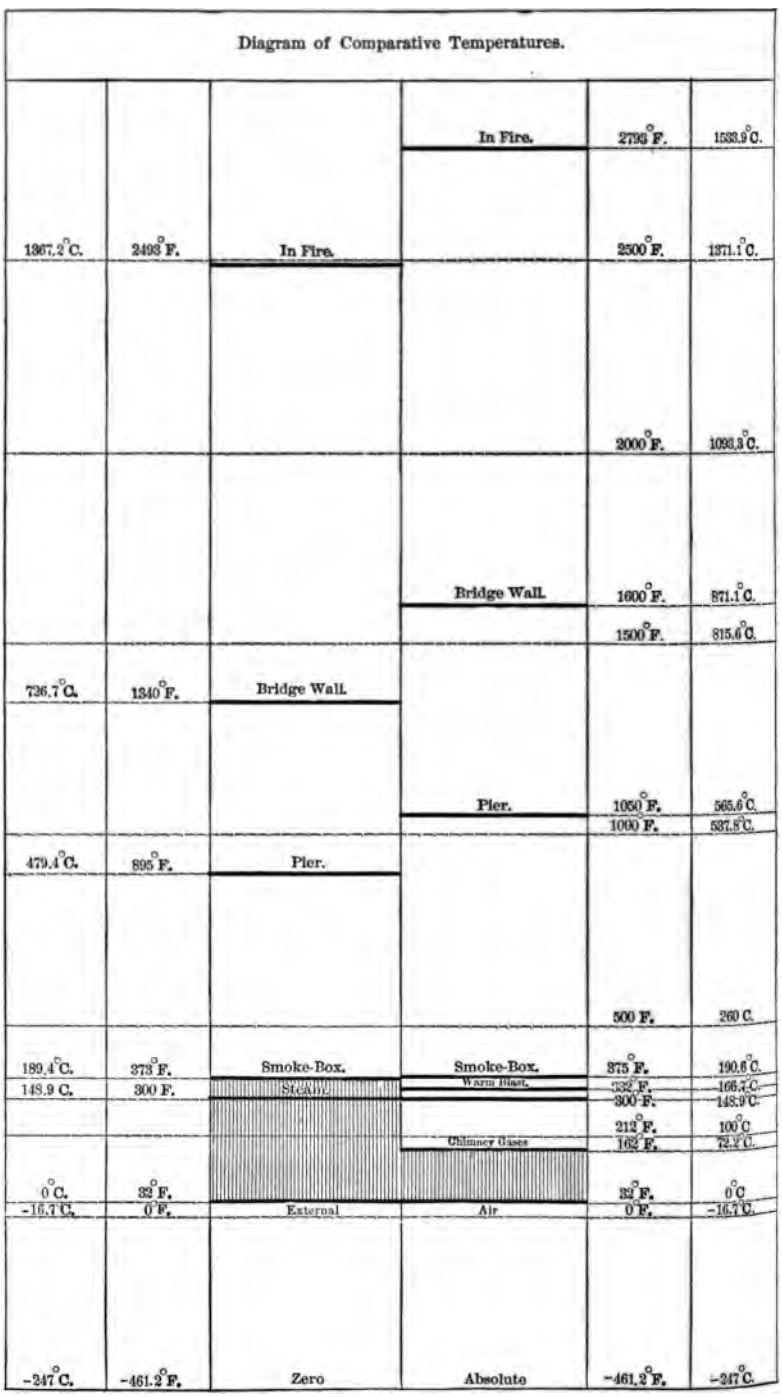
Diagram of Comparative Temperatures.
In Fire.
2796°F.
1533.9°C.
1367.2°C.
2493°F.
In Fire.
2500°F.
1371.1°C.
2000°F.
1093.3°C.
Bridge Wall.
1600°F.
871.1°C.
1500°F.
815.6°C.
736.7°C.
1340°F.
Bridge Wall.
Pier.
1050°F.
565.6°C.
1000°F.
537.8°C.
479.4°C.
895°F.
Pier.
500 F.
260 C.
189.4°C.
373°F.
Smoke-Box.
Smoke-Box.
375°F.
190.6°C.
148.9 C.
300 F.
Steam.
Warm Blast.
332°F.
166.7°C.
300°F.
148.9°C.
212°F.
100°C
Chimney Gases
162°F.
72.2°C.
0°C.
32°F.
32°F.
0°C
-16.7°C.
0°F.
External
Air
0°F.
-16.7°C.
-247°C.
-461.2°F.
Zero
Absolute
-461.2°F.
-247°C.

FIG. 14.

TABLE XXI.

COMPARATIVE TEMPERATURES—PACIFIC AND WARM-BLAST BOILERS UNDER EQUAL CONDITIONS; 20.36 POUNDS OF GASES OF COMBUSTION—IN THE FIRE—PER POUND OF ANTHRACITE COAL, 82 PER CENT. CARBON, COMPLETELY BURNED TO CO_2: EXTERNAL AIR AT 32° FAHR., STEAM PRESSURE, 52.5 POUNDS PER SQUARE INCH ABOVE THE ATMOSPHERE—TEMPERATURE OF STEAM, 300° F.

LOCATION OF TEMPERATURES.	TEMPERATURES: DEGREES FAHR.		
	Pacific Boiler.	Warm-Blast Boiler.	Difference.
In heart of fire	2493°	2793°	300°
At bridge wall	1340°	1600°	260°
At pier	895°	1050°	155°
In smoke-box	373°	375°	2°
Air admitted to furnace	32°	332°	300°
Steam and water in boiler	300°	300°	0°
Gases escaping to chimney	373°	162°	211°
External air	32°	32°	0°
Gases cooled, Warm-Blast Boiler			213°
Air warmed, Warm-Blast Boiler			300°

It will be observed that the air entering the furnace is warmed 300°, while the gases are cooled only 213°. This difference, or something like it, was constantly observed, and may be explained by two causes: *First*, the weight of the gases was about one-twentieth greater than that of the incoming air, by reason of the carbon carried off as CO_2, and (the specific heat of the gases and of air being sensibly alike—0.238), this circumstance alone would bring the cooling of the gases down from 300° to 285°; *second*, the whole mass of brick and iron composing the abstractors was kept at a pretty high temperature by conduction from the boiler setting.

This would tend, of course, to raise the mean between the outgoing gases and the incoming air; that is, to aid the warming of the air, and to retard the cooling of the gases. The mean temperature of the air in abstractor was (32° at entering, 332° at leaving), $\frac{32° + 332°}{2} = 187°$. The mean temperature of the gases in abstractor was (375° at entering, 162° at leaving), $\frac{375° + 162°}{2} = 268.5°$; and $268.5° - 187.0° = 81.5°$.

When the air enters at 32°, the gases are leaving at 162°; and $162° - 32° = 130°$.

When the air leaves, to enter the furnace, at 332°, the gases are entering from the smoke-box, at 375°, and $375° - 332° = 43°$. The mean $\frac{130° + 43°}{2} = 86.5°$, is about the difference to be ex-

pected between two fluids on opposite sides of iron plates, the one imparting heat to the other, at the rate of conduction necessary in steam boilers. It may, perhaps, be reduced to 75°, but it is probable that the enhanced cost of the apparatus would be out of proportion to the gain.

Table XXI. is graphically represented in Figs. 14 and 15. The former sufficiently explains itself, as the several temperatures in Table XXI. are merely located at their proper respective positions, according to the scale chosen.

The base line is the absolute zero of temperatures, 461.2° F. below zero Fahrenheit, equal to 274° C. below zero centigrade. The spaces shaded by heavy vertical lines represent the respective quantities of heat carried off by the chimney.

Fig. 15 represents the same temperatures as they stand related to the surfaces of the shell and flues of the boiler, and to the flues of the abstractors, by means of which heat is withdrawn from the gaseous products of combustion, and imparted to the water in the boiler.

The diminishing rate of absorption with reduction of temperature, as the gases approach the temperature of the absorbing surfaces, is clearly shown.

The gases are, in fact, cooled by the air in the abstractor 138° F. below the temperature of the steam in the boiler, but a very large area is required to do this.

Incidentally, Fig. 15 shows the relative volume of the gases of combustion at successive points. Calling the volume at the temperature of external air (32° F.), equal to 1, it is 6 to 6.6 in the heart of the fire, 3.65 to 4.18 at the bridge wall, 2.75 to 3.06 at the pier, on entering the boiler-flues, 1.69 at the smoke-box, and 1.26 at the blower, where it is discharged to the chimney.

These two diagrams, Fig. 14 and Fig. 15, are a complete summary of the experiments recorded in these pages, so far as they relate to the two modes of boiler setting, with cold blast and warm blast, applied to boilers otherwise exactly alike, under equal conditions.

Analysis of Coals.—The manner of obtaining and preserving samples of coal has been already described. A suitable portion of each sample to be analyzed, separated from the rest with the precautions usual in assaying to insure a fair representation of the whole sample in the part selected, was put into a platinum "boat," weighed, inserted in a glass tube about $\frac{5}{8}$ inch caliber and 24 inches long, and kept at a gentle heat—a little above 100° C.—in the furnace seen in Fig. 17, with a stream of air passing through the tube, to desiccate the coal, until after repeated trials, it came to

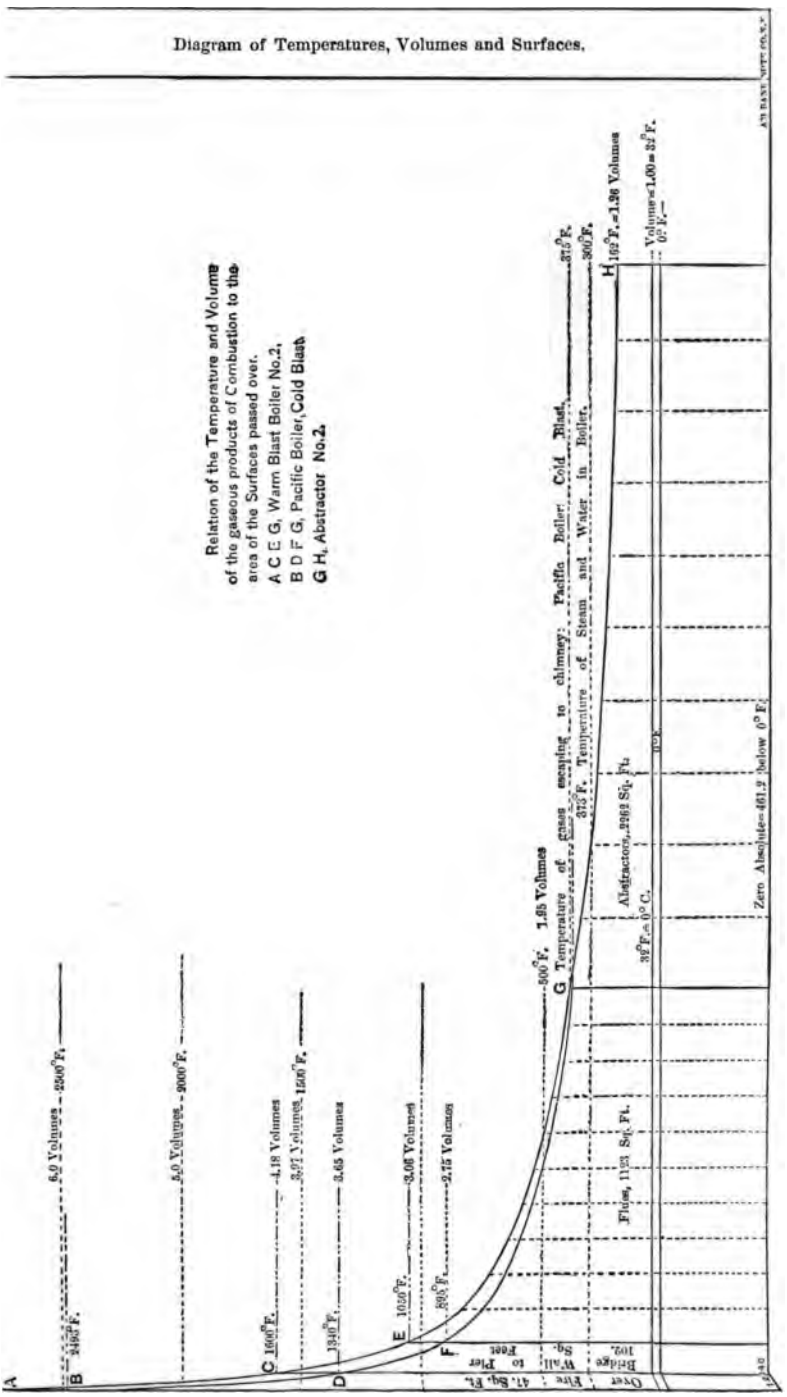
Diagram of Temperatures, Volumes and Surfaces.
Relation of the Temperature and Volume of the gaseous products of Combustion to the area of the Surfaces passed over.
A C E G, Warm Blast Boiler No.2.
B D F G, Pacific Boiler, Cold Blast.
G H, Abstractor No.2.
6.0 Volumes 2500°F.
5.0 Volumes 2000°F.
4.18 Volumes
3.97 Volumes 1500°F.
3.65 Volumes
3.06 Volumes
2.75 Volumes
1.95 Volumes
500°F.
375°F.
300°F.
162°F.=1.26 Volumes
Temperature of gases escaping to chimney: Pacific Boiler, Cold Blast.
375°F. Temperature of Steam and Water in Boiler.
Abstractors, 2262 Sq. Ft.
32°F.=0°C.
Flues, 1123 Sq. Ft.
Zero Absolute=461.2 below 0°F.
Volume=1.00=32°F.
0°F.
Over Bridge 102.
Fire 41. Sq. Ft.
Wall to Pier Feet Sq.

FIG. 15.

constant weight, when it was supposed to be dry. The tube was then connected with a can containing compressed oxygen, the heat was increased, by means of the fifteen Bunsen burners of the furnace, to a moderate red heat, and a stream of oxygen was passed through the tube, until after repeated trials, the boat and its contained coal again came to constant weight—the carbon (and any other combustible substances which may have been present), having been oxidized, leaving in the boat ash only.

The use of oxygen instead of atmospheric air facilitates the oxidation, greatly shortens the process, and not only saves the time of the assistant, but, most important of all, lessens in a still greater degree the danger of losing an analysis through the premature breaking of a tube—a circumstance happening with vexatious frequency when air is used. All analyses were made in duplicate, and in case of suspicious difference, or of accident to one boat, they were repeated until satisfactory agreement was reached.

Passing, after leaving the tube, through a calcium chloride tube and a set of Geissler bulbs, the oxygen leaves its water, derived from oxidation of the hydrogen, in the former, and its CO_2, derived from the oxidation of the carbon, in the latter. The four chief ingredients of the coal—carbon, water, ash, and hydrogen, being thus determined directly, by weight, the remaining possible ingredients—oxygen, sulphur, and nitrogen are, in the anthracites left undistinguished, as a residuum, small in amount, only about 2.8 per cent. in the aggregate. In the bituminous coals, the determination of the sulphur, less than 1 %, and of the oxygen, 4.5 to 5% (in one case), leaves the nitrogen as a residuum, 2 %.

The continuous reservation of samples—at every firing—the systematic preservation of these samples, their uniform treatment, and the great number of duplicate analyses, give reason for considerable confidence in the final mean results.

Calorimetric observations to determine the quantity of entrained water in the steam.—The full notes of all experiments with the calorimeter, made during the entire week, July 11–16, 1881, are subjoined, together with the calculations of results. These experiments were made at various stages of the fire, and under varying conditions of demand for steam, and of rising and falling, and stationary pressure, and are supposed to represent fairly the usual operation of the Pacific Boiler in this respect. In a few instances, noticeably in the three observations on July 14, there is a slight irregularity in the first reading of the thermometer, "after admitting steam," column 7, due, perhaps, to imperfect mixing; but subsequent readings are clear.

TABLE XXII.—CALORIMETRIC OBSERVATIONS, JULY 11, 1881, A.M. (1)

TIME OF READINGS.	WEIGHT OF CALORIMETER AND CONTAINED WATER.		WEIGHT OF CONDENSED STEAM.		TEMPERATURE OF WATER.		DIFFERENCE OF TEMPERATURE.	INTERVAL OF TIME.	STEAM-GAUGE PRESSURE.
	Before admitting steam.	After admitting steam.	By difference.	By wt., after drawing off.	Before admitting steam.	After admitting steam.			
1	2	3	4	5	6	7	8	9	10
A.M.	Lbs. av.	Lbs. av.	Lbs. av.	Lbs. av.	Deg. F.	Deg. F.	Deg. F.	Seconds.	Lbs. per sq. in.
11:48	515.625	521.0625	5.4375	5.6094					
0					57.85°				
1					57.875°				
2					57.9°				
3:05	Steam	let on.			57.925°				
3:50	Steam	shut off.			57.95°	86.575°	28.625°	45	39.9
5						86.55°			
6						86.525°			
7						86.5°			
8						86.475°			

TABLE XXII.—CALORIMETRIC OBSERVATIONS, JULY 11, 1881, P.M.—*Continued.* (2)

TIME OF READINGS.	WEIGHT OF CALORIMETER AND CONTAINED WATER.		WEIGHT OF CONDENSED STEAM.		TEMPERATURE OF WATER.		DIFFERENCE OF TEMPERATURE.	INTERVAL OF TIME.	STEAM-GAUGE PRESSURE.	CALORIMETER: QUALITY OF STEAM.
	Before admitting steam.	After admitting steam.	By difference.	By wt., after drawing off.	Before admitting steam.	After admitting steam.				
1	2	3	4	5	6	7	8	9	10	
P.M.	Lbs. av.	Lbs. av.	Lbs. av.	Lbs. av.	Deg. F.	Deg. F.	Deg. F.	Seconds.	Lbs. per sq. in.	
2:20	517.0625	525.625	8.5625	8.7793						
0					54°					
1					54.0125°					
2					54.025°					
3					54.05°					
4					54.075°					
4:30	Steam	let on.								
5:10	St am	shut off.			54.1°	98.55°	44.45°	40	75.5	
6						98.5°				
7						98.45°				
8						98.4°				
9						98.35°				
10						98.3°				

TABLE XXII. —CALORIMETRIC OBSERVATIONS, JULY 12. 1881, A.M.—*Continued.*

(3)

TIME OF READINGS.	WEIGHT OF CALORIMETER AND CONTAINED WATER.		WEIGHT OF CONDENSED STEAM.		TEMPERATURE OF WATER.		DIFFERENCE OF TEMPERATURE.	INTERVAL OF TIME.	STEAM-GAUGE PRESSURE.	CALORIMETRY: QUALITY OF STEAM.
	Before admitting steam.	After admitting steam.	By difference.	By wt., after drawing off.	Before admitting steam.	After admitting steam.				
1	2	3	4	5	6	7	8	9	10	
A.M.	Lbs. av.	Lbs. av.	Lbs. av.	Lbs. av.	Deg. F.	Deg. F.	Deg. F.	Seconds.	Lbs. per sq. in.	
9:05	517.0625	526.75	9.6875	9.7168						
0					44.775°					
1					44.8°					
2					44.825°					
3					44.85°					
4					44.875°					
4:08	Steam	let on.			44.8875°	94.4°	49.5125°	60	54.2	
5:08	Steam	shut off.								
6						93.325°				
7						93.275°				
8						93.225°				
9						93.175°				
10						93.125°				

TABLE XXII.—CALORIMETRIC OBSERVATIONS, JULY 12, 1881, P.M.—*Continued.* (4)

TIME OF READINGS.	WEIGHT OF CALORIMETER AND CONTAINED WATER.		WEIGHT OF CONDENSED STEAM.		TEMPERATURE OF WATER.		DIFFERENCE OF TEMPERATURE.	INTERVAL OF TIME.	STEAM-GAUGE PRESSURE.	CALORIMETRY: QUALITY OF STEAM.
	Before admitting steam.	After admitting steam.	By difference.	By wt., after drawing off.	Before admitting steam.	After admitting steam.				
1	2	3	4	5	6	7	8	9	10	
P.M.	Lbs. av.	Lbs. av.	Lbs. av.	Lbs. av.	Deg. F.	Deg. F.	Deg. F.	Seconds.	Lbs. per sq. in.	
3:15	516.5625	529.25	12.6875	12.7324						
0					38.175°					
1					38.225°					
2					38.275°					
3					38.325°					
4					38.375°					
4:30	Steam	let on.			38.4°					
5:30	Steam	shut off.			38.45°	102.625°	64.175°	60	75.5	
6						102.6°				
7						102.55°				
8						102.5°				
9						102.45°				
10						102.4°				

TABLE XXII.—CALORIMETRIC OBSERVATIONS, JULY 13, 1881, A.M.—*Continued.* (5)

TIME OF READINGS.	WEIGHT OF CALORIMETER AND CONTAINED WATER.		WEIGHT OF CONDENSED STEAM.		TEMPERATURE OF WATER.		DIFFERENCE OF TEMPERATURE.	INTERVAL OF TIME.	STEAM-GAUGE PRESSURE.	CALORIMETRY: QUALITY OF STEAM.
	Before admitting steam.	After admitting steam.	By difference.	By wt., after drawing off.	Before admitting steam.	After admitting steam.				
1	2	3	4	5	6	7	8	9	10	
A.M.	Lbs. av.	Lbs. av.	Lbs. av.	Lbs. av.	Deg. F.	Deg. F.	Deg. F.	Seconds.	Lbs. per sq. in.	
9:35	518.8125	523.625	4.8125	4.8437						
0					46.475°					
1					46.5°					
2					46.525°					
3	Steam	let on.			46.55°					
4:15	Steam	shut off.			46.575°	71°	24.425°	75	17.5	
5						71°				
6						71°				
7						71°				
8						71°				
9						71°				

TABLE XXII.—CALORIMETRIC OBSERVATIONS, JULY 13, 1881, P.M. (a).—*Continued.* (6)

TIME OF READINGS.	WEIGHT OF CALORIMETER AND CONTAINED WATER.		WEIGHT OF CONDENSED STEAM.		TEMPERATURE OF WATER.		DIFFERENCE OF TEMPERATURE.	INTERVAL OF TIME.	STEAM-GAUGE PRESSURE.	CALORIMETRY: QUALITY OF STEAM.
	Before admitting steam.	After admitting steam.	By difference.	By wt., after drawing off.	Before admitting steam.	After admitting steam.				
1	2	3	4	5	6	7	8	9	10	
P.M.	Lbs. av.	Lbs. av.	Lbs. av.	Lbs. av.	Deg. F.	Deg. F.	Deg. F.	Seconds.	Lbs. per sq. in.	
3:05	517.5	524.25	6.75	6.8984						
0					51.5°					
1					51.5°					
2					51.25°					
3	Steam	let on.			51.55°					
3:50	Steam	shut off.			51.575°	86.4°	34.825	50	41.3	
5						86.4°				
6						86.35°				
7						86.35°				
8						86.3°				
9						86.3°				

TABLE XXII.—CALORIMETRIC OBSERVATIONS, JULY 18, 1881, P.M. (b).—*Continued.* (7)

TIME OF READINGS.	WEIGHT OF CALORIMETER AND CONTAINED WATER.		WEIGHT OF CONDENSED STEAM.		TEMPERATURE OF WATER.		DIFFERENCE OF TEMPERATURE.	INTERVAL OF TIME.	STEAM-GAUGE PRESSURE.	CALORIMETRY; QUALITY OF STEAM.
	Before admitting steam.	After admitting steam.	By difference.	By wt., after drawing off.	Before admitting steam.	After admitting steam.				
1	2	3	4	5	6	7	8	9	10	
A.M.	Lbs. av.	Lbs. av.	Lbs. av.	Lbs. av.	Deg. F.	Deg. F.	Deg. F.	Seconds.	Lbs. per sq. in.	
5:15	518.25	525.50	7.25	7.1445						
0					51.225°					
1					51.25°					
2					51.275°					
3	Steam	let on.			51.325°					
3:45	Steam	shut off.			51.35°	87.575°	36.225°	45	50.7	
4						87.55°				
5						87.525°				
6						87.5°				
7						87.475°				
8						87.45°				
9						87.425°				

TABLE XXII.—CALORIMETRIC OBSERVATIONS, JULY 14, 1881, A.M.—*Continued.* (8)

TIME OF READINGS.	WEIGHT OF CALORIMETER AND CONTAINED WATER.		WEIGHT OF CONDENSED STEAM.		TEMPERATURE OF WATER.		DIFFERENCE OF TEMPERATURE.	INTERVAL OF TIME.	STEAM-GAUGE PRESSURE.
	Before admitting steam.	After admitting steam.	By difference.	By wt., after drawing off.	Before admitting steam.	After admitting steam.			
1	2	3	4	5	6	7	8	9	10
A.M.	Lbs. av.	Lbs. av.	Lbs. av	Lbs. av.	Deg. F.	Deg. F.	Deg. F.	Seconds.	Lbs. per sq. in.
9:30	517.625	525.3125	7.6875	7.7812					
0					37.9°				
1					37 925°				
2					37.95°				
3	Steam	let on.			37.975°				
3:50	Steam	shut off.			38.°	77.65°	39.65°	50	49.1
4									
5									
6						78°(?)			
7						77.525°			
8						77.5°			
9						77.475°			
10						77.45°			
11						77.425°			

TABLE XXII.—CALORIMETRIC OBSERVATIONS, JULY 14, 1881, A.M. (a).—*Continued.*

TIME OF READINGS.	WEIGHT OF CALORIMETER AND CONTAINED WATER.		WEIGHT OF CONDENSED STEAM.		TEMPERATURE OF WATER.		DIFFERENCE OF TEMPERATURE.	INTERVAL OF TIME.	STEAM-GAUGE PRESSURE.
	Before admitting steam.	After admitting steam.	By difference.	By wt., after drawing off.	Before admitting steam.	After admitting steam.			
1	2	3	4	5	6	7	8	9	10
P.M.	Lbs. av.	Lbs. av.	Lbs. av.	Lbs. av.	Deg. F.	Deg. F.	Deg. F.	Seconds.	Lbs. per sq. in.
3:45	515.5625	525.25	9.6875						
0					43.5°				
1					43.525°				
2					43.55°				
3					43.575°				
4	Steam	let on.			43.6°				
5:30	Steam	shut off.			43.625°	93.075°	49.45°	90	36.6
6									
7						93.45° (?)			
8				9.6718		93.°			
9						92.975°			
10						92.925°			
11						92.9°			
12						92.875°			

TABLE XXII.—CALORIMETRIC OBSERVATIONS, JULY 14, 1891, P.M. (b).—*Continued.* (10)

TIME OF READINGS.	WEIGHT OF CALORIMETER AND CONTAINED WATER		WEIGHT OF CONDENSED STEAM.		TEMPERATURE OF WATER.		DIFFERENCE OF TEMPERATURE.	INTERVAL OF TIME.	STEAM-GAUGE PRESSURE.	CALORIMETER: QUALITY OF STEAM.
	Before admitting steam	After admitting steam	By difference	By wt., after drawing off	Before admitting steam	After admitting steam.				
1	2	3	4	5	6	7	8	9	10	
P.M.	Lbs. av.	Lbs. av.	Lbs. av.	Lbs. av.	Deg. F.	Deg. F.	Deg. F.	Seconds.	Lbs. per sq. in.	
h m.	818.878	828.828	9.70	9.7000						
0					80.80°					
1					80.170°					
2					80.4°					
3					80.490°					
4	Steam	let on.			80.4h°					
4:4h	Steam	shut off.			80.47h	86.8°	80.720°	45	115.0	
5										
6						86.1° (?)				
7						86.06°				
8						85.970°				
9						85.90°				
10						85.8°				

TABLE XXII.—CALORIMETRIC OBSERVATIONS, JULY 15, 1881, A.M.—*Continued.*

TIME OF READINGS.	WEIGHT OF CALORIMETER AND CONTAINED WATER.		WEIGHT OF CONDENSED STEAM.		TEMPERATURE OF WATER.		DIFFERENCE OF TEMPERATURE.	INTERVAL OF TIME.	STEAM-GAUGE PRESSURE.
	Before admitting steam.	After admitting steam.	By difference.	By wt., after drawing off.	Before admitting steam.	After admitting steam.			
1	2	3	4	5	6	7	8	9	10
A.M.	Lbs. av.	Lbs. av.	Lbs. av.	Lbs. av.	Deg. F.	Deg. F.	Deg. F.	Seconds.	Lbs. per sq. in.
9:10	517.375	526.875	9.5	9.496					
0					39.95°				
1					39.975°				
2					40°				
3	Steam	let on.			40.025°				
3:45	Steam	shut off.			40.05°	88.425°	48.375°	45	67.8
4									
5									
6						88.375°			
7						88.35°			
8						88.325°			
9						88.3°			
10						88.275°			

TABLE XXII.—CALORIMETRIC OBSERVATIONS, JULY 15, 1881, P.M. (a).—*Continued.* (12)

TIME OF READINGS.	WEIGHT OF CALORIMETER AND CONTAINED WATER.		WEIGHT OF CONDENSED STEAM.		TEMPERATURE OF WATER.		DIFFERENCE OF TEMPERATURE.	INTERVAL OF TIME.	STEAM-GAUGE PRESSURE.
	Before admitting steam.	After admitting steam.	By difference.	By wt., after drawing off.	Before admitting steam.	After admitting steam.			
1	2	3	4	5	6	7	8	9	10
P.M.	Lbs. av.	Lbs. av.	Lbs. av.	Lbs. av.	Deg. F.	Deg. F.	Deg. F.	Seconds.	Lbs. per sq. in.
1:40	518.5	528.4375	9.9375	9.7617					
0					41.825°				
1					41.85°				
2					41.875°				
3					41.9°				
4	Steam	let on.							
5:30	Steam	shut off.			41.95°	91.8°	49.85°	90	75.0°
6									
7									
8						91.65°			
9						91.6°			
10						91.55°			
11						91.5°			
12						91.45°			

TABLE XXII.—CALORIMETRIC OBSERVATIONS, JULY 15, 1881, P. M. (b).—*Continued.* (13)

TIME OF READINGS.	WEIGHT OF CALORIMETER AND CONTAINED WATER.		WEIGHT OF CONDENSED STEAM.		TEMPERATURE OF WATER.		DIFFERENCE OF TEMPERATURE.	INTERVAL OF TIME.	STEAM-GAUGE PRESSURE.	CALORIMETRY: QUALITY OF STEAM.
	Before admitting steam.	After admitting steam.	By difference.	By wt., after drawing off.	Before admitting steam.	After admitting steam.				
1	2	3	4	5	6	7	8	9	10	
P.M.	Lbs. av.	Lbs. av.	Lbs. av.	Lbs. av.	Deg. F.	Deg. F.	Deg. F.	Seconds.	Lbs. per sq. in.	
5:55	518.6875	531.3125	12.625	12.6289						
0					41.5°					
1					41.525°					
2					41.55°					
3					41.575°					
4	Steam	let on.			41.6°					
5					41.625°					
6					41.65°	104°	62.25°	180	24.9	
7	Steam	shut off.				103.95°				
8						103.925°				
9						103.9°				
10						103.875°				
11						103.8°				

TABLE XXII.—CALORIMETRIC OBSERVATIONS, JULY 16, 1881, A.M.—*Continued.* (14)

TIME OF READINGS.	WEIGHT OF CALORIMETER AND CONTAINED WATER.		WEIGHT OF CONDENSED STEAM.		TEMPERATURE OF WATER.		DIFFERENCE OF TEMPERATURE.	INTERVAL OF TIME.	STEAM-GAUGE PRESSURE.
	Before admitting steam.	After admitting steam.	By difference.	By wt., after drawing off.	Before admitting steam.	After admitting steam.			
1	2	3	4	5	6	7	8	9	10
A.M.	Lbs. av.	Lbs. av.	Lbs. av.	Lbs. av.	Deg. F.	Deg. F.	Deg. F.	Seconds.	Lbs. per sq. in.
11:05	518.25	526.1875	7.9375	7.92					
0					42.025°				
1					42.05°				
2					42.075°				
3	Steam	let on.							
4:15	Steam	shut off.			42.125°	82.6°	40.475°	75	33.4
5									
6						82.6° (?)			
7						82.5°			
8						82.45°			
9						82.475°			
10						82.4°			

Calculation of the quantity of entrained water in steam, from data obtained by calorimetric observations, Monday, July 11, 1881, 11h. 43m. A.M. given in detail in Table XXII. (1), p. 91.

Barometer, corrected reading	in.	29.79
Corresponding atmospheric pressure	lbs. per sq. in.	14.63
Boiler pressure by steam gauge	" "	39.90
Steam pressure absolute	" "	54.53
Number of British thermal units above 0° F. contained in 1 lb. of saturated steam of 54.53 lbs. per sq. in. absolute pressure	B. t. u.	1201.2755
Number of B. t. u. contained in 1 lb. of water of 86.575° F. (also above 0° F.)	B. t. u.	86.6232
Number of B. t. u. given up by 1 lb. of saturated steam of 54.53 lbs. per sq. in. absolute pressure condensed and cooled to 86.575° F	B. t. u.	1114.6523
Number of B. t. u. which would be given up by 5.6094 lbs. of saturated steam of 54.53 lbs. per sq. in. absolute pressure, by condensation at 86.575°; 1114.6523 × 5.6094 =	B. t. u.	6252.5306
Gross weight of calorimeter and water therein contained, before admitting steam, col. 2	lbs.	515.625
Weight of calorimeter, empty	lbs.	317.625
Net weight of water in calorimeter	lbs.	198.
Heat capacity of calorimeter, in equivalent weight of water	lbs.	17.2
Calorific value in B. t. u. of calorimeter and contents	lbs.	215.2
Number of B. t. u. contained in water at 86.575°; brought forward	B. t. u.	86.6232
Number of B. t. u. contained in water at 57.95 (col. 4, p. 707.)	B. t. u.	57.9570
Number of B. t. u. actually gained by each 1 lb. of water raised from 57.95° F to 86.575° F	B. t. u.	28.6662
Number of B. t. u. gained by 215.2 lbs of water, including the equivalent for the calorimeter, in rising from 57.95° to 86.575; 215.2 × 28.6662	B. t. u.	6168.9662
Excess of the number of B. t. u. which would have been given up by saturated steam, over the number actually gained by the water, = 6252.5306 − 6168.9662	B. t. u.	83.5644
Ratio of this excess to the number which would have been given up by 5.6094 lbs. of saturated steam of 54.53 lbs. per sq in. absolute pressure, condensed at 86.575° F., = 83.5644 ÷ 6252.5306 =	Ratio.	.013365

It therefore appears that the 5.6094 lbs. of actual "steam" admitted to the calorimeter was not saturated steam, but a mixture of saturated steam and water of equal temperature, in such proportions as to require 1.3365 per cent. of the quantity of heat which 5.6094 lbs. of saturated steam of 54.53 lbs. per square inch pressure absolute would have given in condensing at 86.575° F., to complete the evaporation of the entrained water.

The temperature of the steam and water alike is..	Deg. F.	286.3457
The number of B. t. u. above 0° F. contained in water of temperature 286.3457° F. is	B. t. u.	288.5885
From this number subtract the number of B. t. u. above 0° F. contained in water of temperature 86.575° F.....	B. t. u.	86.6232
And we have the number of B. t. u. imparted per pound of water, between 286.3457° and 86.575° F.	B. t. u.	201.9653

Each pound of saturated steam of 54.53 lbs. per square inch pressure absolute, and therefore of 286.3457° F. temperature, contains, as we have seen, 1201.2755 B. t. u., and in condensing and cooling to 86.575° F., must give out, 1201.2755 − 86.6232 = 1114.6523 B. t. u., and 1114.6523 ÷ 201.9653 = 5.5190, the ratio of the heating power of unit weight of steam to that of unit weight of water of this temperature. These two fluids, then, steam and water, are in this instance, mixed in such proportions that 5.6094 pounds of the mixture give out, in cooling from 286.3457° to 86.575° F., 6168.9662 B. t. u. A few trials enable us to determine that 98.365 per cent. of the 5.6094 pounds of the mixture, amounting to 5.5177 pounds, are steam, giving out:

TABLE XXIII.

QUANTITY OF HEAT LOST BY STEAM AND GAINED BY WATER.

5.5177 × 1114.6523 = ...	B. t. u.	6150.3170
And that 100 − 98.365 − 1.635 per cent., amounting to 0.0917 pounds, are water, giving out 0.0917 × 201.9653 = ...	B. t. u.	18.5202
Making a total of.....	.....	6168.8372
Which is substantially equal to the heat in B. t. u. gained by the water; = 215.2 × 28.6662 = ...	B. t. u.	6168.9662

Calculations similar to the foregoing applied to the data obtained by calorimetric observations at other times during the week, July 11–16, as given in Table XXII. (1) to (14), give results which, with the one above given in detail, are tabulated below.

TABLE XXIV.

REDUCTION OF CALORIMETRIC OBSERVATIONS. (1)

NO.	Day in July, 1881, when experiments were made, and hour and minute of beginning of experiment.			PRESSURES: ATMOS. AND STEAM.				TEMPERATURES.	
				Barometer.		Steam gauge.			
	Day of month.	Part of day.	H. M.	Inches of mercury, corrected to 32° F.	Pressure of atmos., lbs. per sq. in.	Boiler press. above atmos., lbs. per sq. in.	Boiler press. absolute, lbs. per sq. in.	Of steam admitted to calorimeter and entrained water, Degrees F.	Of water condensed in calorimeter and entrained water, Degrees F.
1	2	3	4	5	6	7	8	9	10
1	11	A.M.	11:48	29.79	14.63	39.9	54.53	286.3456	86.575
2	11	P.M.	2:20	29.80	14.64	75.5	90.14	320.1485	98.55
3	12	A.M.	9:5	29.69	14.58	54.2	68.78	301.5381	94.4
4	12	P.M.	3:15	29.63	14.55	75.5	90.05	320.0781	102.625
5	13	A.M.	9:35	29.52	14.50	17.5	32.00	253.9520	71.
6	13	P.M.	3:5	29.45	14.46	41.3	55.76	287.7748	86.4
7	13	P.M.	5:15	29.42	14.45	50.7	65.15	297.9286	87.575
8	14	A.M.	9:30	29.45	14.46	49.1	63.56	310.5596	77.65
9	14	P.M.	3:45	29.48	14.48	36.6	51.08	282.1972	93.075
10	14	P.M.	5:30	29.51	14.49	65.0	79.49	311.4098	86.2
11	15	A.M.	9:10	29.66	14.57	67.8	82.37	313.8312	88.425
12	15	P.M.	1:40	29.63	14.55	75.0	89.55	319.6835	91.8
13	15	P.M.	5:55	29.59	14.53	24.9	39.43	266.2530	104.
14	16	A.M.	11:5	29.30	14.39	33.4	47.79	278.0217	82.6
	Means.....						64.98	296.4087	89.3482

TABLE XXIV.—REDUCTION OF CALORIMETRIC OBSERVATIONS.—*Continued.* (2)

	BRITISH THERMAL UNITS.			Weight of water condensed in steam-drum of calorimeter during experiment.	Total B. t. u. which would have been imparted to the water if the steam had been saturated, dry steam.
	Contained in one pound of saturated steam of given absolute pressure	Contained in one pound of water condensed in steam-drum of calorimeter.	Which would have been imparted to the water if the steam had been saturated.		
No.	B. t. u. per lb.	B. t. u. per lb.	B. t. u. per lb.	Pounds av.	Total B. t. u.
1	11	12	13	14	15
1	1201.2755	86.6232	1114.6523	5.5324 .0770 5.6094	6252.5306
2	1211.5858	98.6257	1112.9601	8.6611 .1182 8.7793	9771.0106
3	1205.9092	94.4638	1111.4454	9.6603 .0565 9.7168	10799.6927
4	1211.5637	102.7129	1108.8508	12.5134 .2190 12.7324	14118.3319
5	1191.3882	71.0210	1120.3672	4.7630 .0807 4.8437	5426.7226
6	1201.7115	86.4478	1115.2637	6.7833 .1151 6.8984	7693.5351
7	1204.8084	87.6252	1117.1832	7.0696 .0749 7.1445	7981.7154
8	1204.3102	77.6813	1126.6289	7.6453 .1359 7.7812	8766.5248
9	1200.0106	93.1362	1106.8694	9.6207 .0511 9.6718	10705.4195
10	1208.9076	86.2474	1122.6602	9.7425 .0270 9.7695	10967.8288
11	1209.6584	88.4769	1121.1815	9.3648 .1312 9.4960	10646.7395
12	1211.4434	91.8586	1119.5848	9.7192 .0425 9.7617	10929.0509
13	1195.1463	104.0920	1091.0543	12.4828 .1461 12.6289	13778.8156
14	1193.7372	82.6402	1116.0970	7.9065 .0135 7.9200	8839.4882
Mean by weighing				8.7681	9762.6719
Mean by difference				8.7366	
Mean apparent error				.0315	
				8.66185 .10625	
				8.76810	

TABLE XXIV.—*Continued.*

REDUCTION OF CALORIMETRIC OBSERVATIONS. (3)

No.	Weight of water in calorimeter including thermal equivalent of calorimeter.	Temperature of water in calorimeter just before admitting steam.	B. t. u. contained in one pound of water in calorimeter before admitting steam.	B. t. u. imparted to one pound of water raised from initial to final temperature.	Total heat gained by the water in column 16 in being raised from t in column 17 to temperature in column 10.	Deficit of heat due to water entrained in the steam. Difference of columns 15 and 20.
	Lbs. av.	Deg. F.	B. t. u.	B. t. u.	Total B. t. u.	B. t. u.
1	16	17	18	19	20	21
1	215.2	57.95	57.9570	28.6662	6168.9662	83.5644
2	216.6375	54.1	54.1051	44.5206	9644.8315	126.1791
3	216.6375	44.8875	44.8895	49.5743	10739.6524	60.0403
4	216.1375	38.45	38.4505	64.2624	13889.5145	228.8174
5	218.3875	46.575	46.5770	24.4440	5338.2641	88.4585
6	217.075	51.575	51.5790	34.8688	7569.1448	124 3903
7	217.825	51.35	51.3540	36.2712	7900.7741	80.9413
8	217.2	38	38.0000	39.6813	8618.7784	147.7464
9	215.1375	43.625	43.6266	49.5096	10651.3716	54.0479
10	215.45	35.475	35.4750	50.7724	10938.8709	28.9579
11	216.95	40.05	40.0510	48.4259	10505.9990	140.7405
12	218.075	41.95	41.9510	49.9076	10883.5999	45.4510
13	218.2625	41.65	41.6510	62.4410	13628.5288	150.2868
14	217.825	42.125	42.1260	40.5142	8825.0056	14.4826
	216.9143	44.84	Means	Means	9664.5216	98.1503

TABLE XXIV.—*Continued.*

REDUCTION OF CALORIMETRIC OBSERVATIONS. (4)

	Day in July, 1881, when experiments were made, and hour and minute of beginning of experiments.				BRITISH THERMAL UNITS.		RATIO: PER CENT.	
	Day of week.	Part of day.	Day of month.	H. M.	Gained by the water in column 16, in being raised from initial to final temperature.	Which would have been imparted to the water if the steam had been saturated: dry.	Heat required to evaporate the entrained water.	Ratio of entrained water to total water and steam.
					B. t. u.	B. t. u.	Per cent.	Per cent.
1	22	23	24	25	26	27	28	29
1	Monday	A.M.	11	11:48	6168.97	6252.53	1.34	1.37
2	"	P.M.	11	2:20	9644.83	9771.01	1.29	1.35
3	Tuesday	A.M.	12	9:5	10739.65	10799.69	.55	.58
4	"	P.M.	12	3:15	13889.51	14118.33	1.62	1.72
5	Wed'day	A.M.	13	9:35	5338.26	5426.72	1.63	1.67
6	"	P.M.	13	3:5	7569.14	7693.54	1.62	1.67
7	"	P.M.	13	5:15	7900.77	7981.72	1.01	1.05
8	Thursd'y	A.M.	14	9:30	8618.78	8766.52	1.69	1.75
9	"	P.M.	14	3:45	10651.37	10705.42	.50	.53
10	"	P.M.	14	5:30	10938.87	10967.83	.26	.28
11	Friday	A.M.	15	9:10	10506.00	10646.74	1.32	1.38
12	"	P.M.	15	1:40	10883.60	10929.05	.42	.44
13	"	P.M.	15	5:55	13628.53	13778.82	1.09	1.16
14	Saturday	A.M.	16	11:5	8825.01	8839.49	.16	.17
	Means				9664.52	9762.67		
	Mean ratios, per cent.						1.04	1.08

A few words as to the possible limits of error in these observations and results may be of interest.

Mean weight of water, including 17.2 lbs. for calorimeter, col. 16	lbs.	216.9143
Gross weight, after admitting steam	lbs.	526.0759
Gross weight, before admitting steam	lbs.	517.3393
Mean weight of steam, by difference	lbs.	8.7366
Mean by separate weighing, col. 14	lbs.	8.7681
Mean sum of errors	lbs.	.0315
Greatest possible error in separate weighing, say 7 grains	lbs.	.0010
Greatest probable error in weight of water in calorimeter	lbs.	.0300
Greatest probable error in pressure by steam gauge and barometer	lb. per sq. in.	0.1000
Greatest probable error in temperatures; thermometers graduated to tenths of a degree F	Deg. F.	0.1000

In the following table, Table XXV., all the assumed errors are added to the mean in the left-hand column, headed "maximum" and subtracted in the right-hand column, headed "minimum," except in the third line, t_2, temperature of water, final. The difference, or assumed error is here subtracted in the left-hand column, and added in the right-hand column, since this tends to magnify the error in the final result. It will be noticed that the mean deficit of heat, per cent., in this table—last line but one of middle column, is 1.16%, while in Table XXIV., it is 1.04%—of course because the mean of the separate calculations ought not to agree with the result of a calculation based on means of the observations. The wide variation from the mean—almost 40 per cent. each way—*may* occur in single observations, but are not probable, since errors are not unlikely to balance each other in some degree. In our case, with so many as fourteen observations, the mean result seems entitled to some degree of confidence.

If the assumed errors in the third line are transposed, and the maximum be put into the left-hand column, as in all the other cases, the variation in the final result almost disappears—the three numbers in the line next to the bottom—deficit of heat, per cent., become respectively 1.15, 1.16, 1.17. There is no constant ratio between the figures in column 28, Table XXIV., and those in column 29, the latter being affected by variations of final water temperature (column 10) and steam pressure and temperature (columns 8 and 9).

TABLE XXV.

LIMITS OF ERROR IN CALORIMETRIC WORK.

The numbers in this column, right-hand, refer to the headings of columns in Table XXIV.	NO.	KIND OF QUANTITY.	MAXIMUM.	MEAN.	MINIMUM.
P, pressure absolute	8	Lbs. per sq. in.	65.08	64.98	64.88
t, temp. of steam	9	Degrees F.	297.8587	297.7565	297.6540
t_2, of water, final	10	Degrees F.	89.2482	89.3482	89.4482
In 1 lb. of steam	11	B. t. u.	1204.7868	1204.7558	1204.7246
In 1 lb. of water	12	B. t. u.	89.3017	89.4018	89.5021
Difference	13	B. t. u.	1115.4851	1115.3540	1115.2225
				8.66185	
				.10625	
w, weight of steam	14	Lbs.	8.7691	8.7681	8.7671
Total heat	15	B. t. u.	9781.8004	9779.5354	9777.2672
W, weight of water	16	Lbs.	216.9443	216.9143	216.8843
t, of water, initial	17	Degrees F.	44.94	44.84	44.74
In water	18	B. t. u.	44.9419	44.8417	44.7415
89.3017—44.9419, etc.	19	B. t. u.	44.3598	44.5601	44.7606
Total heat	20	B. t. u.	9623.6058	9665.7229	9707.8714
Deficit of heat	21	B. t. u.	158.1946	113.8125	69.3958
Deficit of heat	28	Per cent.	1.617	1.164	0.710
Water in steam	29	Per cent.	1.683	1.212	0.739

Continuous analysis of flue gases.—It would be out of place here to attempt a full description of the process of analysis pursued with the gaseous products of combustion, drawn from the descending smoke-flue near the blower. Such a description would seem to a chemist impertinent, and to others than chemists, pedantic. In brief, it was the gravimetric process, and was conducted as follows:

Samples of considerable volume were obtained through the mixing-box shown in Fig. 16, two of which were set in the flue,

one over the other, one foot apart, with the pipes disposed differently, so as to bring long pipes over short ones, next to the longest over next to the shortest, and only the ends of the central pipe of each group of five over the ends of the corresponding pipes below them; by which arrangement samples from the two boxes proved,

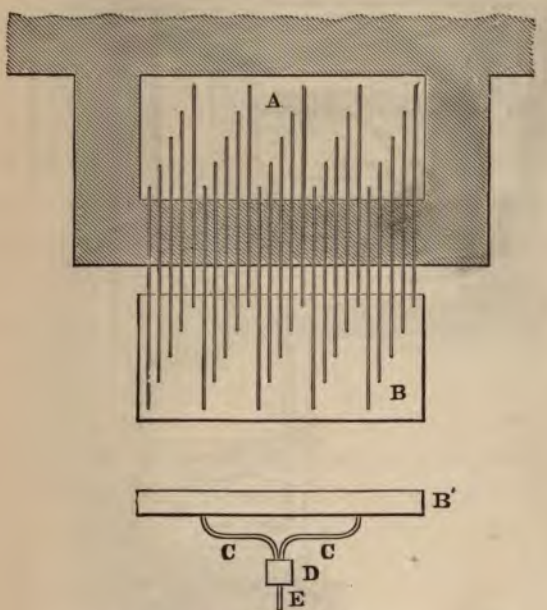

FIG. 16.

MIXING-BOX, FOR OBTAINING SAMPLES OF FLUE GASES FOR ANALYSIS.

A, Section of flue.
B, Section of mixing-box, showing the arrangement of the 25 pipes of ¼ inch gas-pipe.
B′, Front elevation of mixing-box.
C, C, Pipes, four in number, from mixing-box to mixing chamber.
D, Mixing chamber.
E, Discharge-pipe leading to aspirator.

by their agreement, that they truly represented the heterogeneous assemblage of unmixed gases passing through the flue. The greater part of the samples so drawn off by the aspirator was permitted to go to waste; but a small stream was drawn out into a jar filled with glycerine, which flowed out in drops in regulated quantity, to be constantly replaced by the sample of gases. The small stream of gases so drawn off was divided, part going to each one

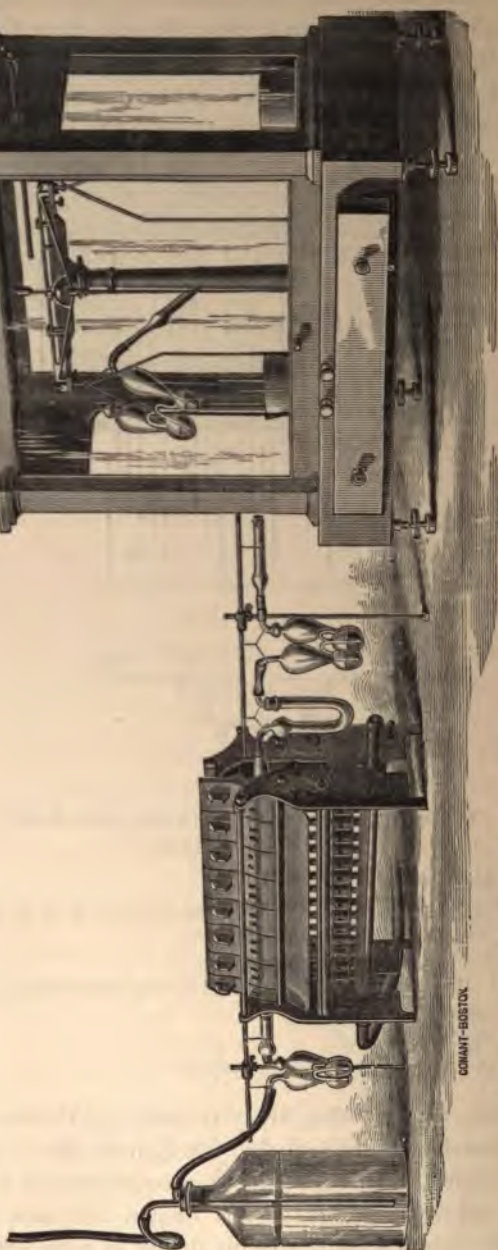

FIG. 17.—APPARATUS FOR CONTINUOUS ANALYSIS OF FLUE GASES BY THE GRAVIMETRIC METHOD.

of two exactly similar sets of Geissler bulbs, first, however, passing through a bulbous tube, Fig. 18, which will arrest any liquid water condensed from vapor in the gases, and then through the U tube, also seen in the figure, which is filled with calcium chloride, and will (if kept at a low temperature, by surrounding it with crushed ice) take up all moisture, and leave the fixed gases completely dry. The dry gases next pass on to and through the group of three Geissler bulbs, each one filled about three-fourths full of hydrate of potash, *i. e.*, a saturated solution of caustic potash. At each drop of liquid, a small bubble of the mixed gases passes down through a central tube nearly to the bottom of the first bulb, and rises as a bubble through the hydrate of potash, to the space above the surface of the liquid, dismissing, simultaneously, a similar bubble at the bottom of the second bulb, which in turn, and simultaneously, dismisses a third bubble into the last bulb, and liberates a similar bubble to pass to and slowly through the second straight, horizontal, bulbous tube, seen at the left-hand of the Geissler bulbs in Fig. 18. This bulbous tube is filled with dry caustic potash, which absorbs all moisture which may have been taken up by the dry gases in their passage through the hydrate of potash, so that the latter suffers no loss of weight—this bulbous tube and the set of Geissler bulbs being weighed together, as seen in Fig. 17. The carbon dioxide (CO_2) contained in the mixed gases is taken up by the hydrate of potash, rapidly by that in the first bulb, which soon presents a nacreous appearance, more slowly by the second, which gradually becomes opalescent, and still more slowly by the third, which is very slightly affected, as nearly all the CO_2 is absorbed in the first and second bulbs.

Some water is taken up by the dry gases, and possibly a little CO_2 along with it; but the dry caustic potash arrests both. The gases, deprived of their moisture and of their carbon dioxide, pass on to the left, to and through a glass tube about 0.6 inch in diameter and 20 inches long, seen about the middle of Fig. 18, extending through a small gas furnace.

This tube has two porous plugs of fibrous asbestos, about six inches apart, near the middle of its length, and the space between these plugs is filled with copper scale (oxide of copper), which is kept at a low red heat by the gas furnace. The gases, which, it will be remembered, now consist solely of oxygen, nitrogen and carbon monoxide (O, N, and CO), are changed, in passing through the hot copper scale, by the complete oxidation of the carbon in the

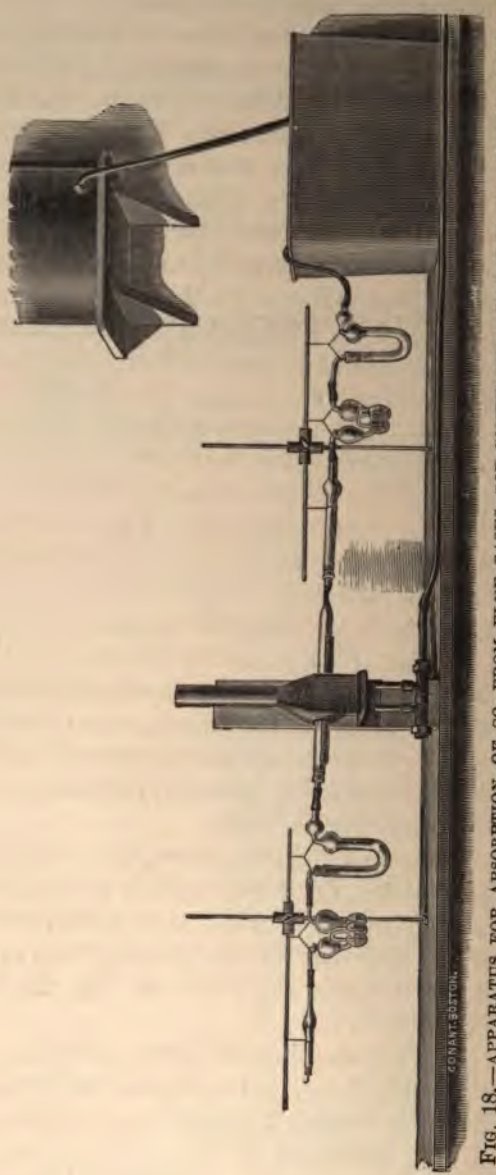

FIG. 18.—APPARATUS FOR ABSORPTION OF CO_2 FROM FLUE GASES, FOR CONVERSION OF CO INTO CO_2, AND FOR THE ABSORPTION OF THE RESULTING CO_2, IN THE CONTINUOUS ANALYSIS OF FLUE GASES. THE COURSE OF THE GASES IS FROM RIGHT TO LEFT.

CO, and the conversion of the CO and additional oxygen into CO_2. It is not easy—for a layman—to see just what office the copper scale performs that would not be as well performed by sand, or bits of fire-brick, since there is always an abundant supply of oxygen present in the surplus air. But the copper oxide would supply oxygen if there were none other present, and may act in some unexplained manner to promote oxidation of the CO. It is also possible that the dissociation of copper and oxygen offers less resistance than the mere mechanical obstruction of the nitrogen and carbon dioxide, after the free oxygen in the flue gases has been reduced as low as 10 per cent. Some experiments cited by Angus Smith in *Air and Rain*, make this seem probable. An analogy is found in the case of iron, which burns eagerly in pure oxygen, but is rendered incombustible in common air, containing 21 per cent. of oxygen, by the mechanical obstruction of the 79 per cent. of nitrogen. However this may be, the carbon which enters the tube as carbon monoxide (CO), leaves it as carbon dioxide (CO_2). Passing on through a second set of potash bulbs, supplemented as before with a dry potash tube, this CO_2 is all absorbed, and the residuary gases, oxygen and nitrogen, are received in a bottle over water (or glycerine), and stored for measurement.

This measurement is readily effected by weighing the liquid drawn off to make room for the gases. The weight and temperature of this liquid (and its specific gravity, also, if other than water) being ascertained, its volume becomes known; the tension of the gases is made equal to that of the atmosphere, which is ascertained by the barometer; and their temperature being also noted, their weight becomes known. From the weight of these residuary gases, and that of the carbon dioxide and the carbon monoxide separated from them, the weight of the original, dry, composite, or mixed gases is readily deducible. The absolute weight of the carbon dioxide obtained, is found by directly weighing the potash bulbs and tube, as seen attached to the scale-beam in Fig. 17, before and after the experiment. The difference is the weight of the CO_2 taken up by the potash, of which $\frac{3}{11}$ is carbon and $\frac{8}{11}$ oxygen.

The weight of the carbon monoxide is ascertained, indirectly, in a similar manner. The difference in weight before and after the experiment is again CO_2, of which all the carbon, $\frac{3}{11}$, and one-half the oxygen, $\frac{4}{11}$, are derived from the gases in the form of CO, and the remaining $\frac{4}{11}$, oxygen, derived from the free oxygen in the surplus air, or from the copper oxide.

Sulphur, in burning, forms chiefly sulphurous acid (SO_2), and a small quantity of sulphuric acid ($H_2O + SO_3 = H_2SO_4$), both of which are taken up by the water. A small quantity of CO_2 is also absorbed by the water, but this soon becomes saturated with CO_2, while it will continue to absorb sulphuric acid and sulphurous acid for some time. It is better, however, to use glycerine.

The quantity of H_2SO_4 is so small as to render its accurate determination difficult in the flue gases, diluted as these are with air. The considerable increase in the quantity of ammonia found in the gases of the warm-blast boiler, makes it probable that all the sulphuric acid exists as a sulphate, mainly sulphate of ammonia.

Carbonate of ammonia was also produced in the warm-blast boiler in considerable quantities, coating all the smoke passages as white as the bolt-trough of a flouring mill.

It is chiefly for the determination of the quantity of carbon dioxide, of carbon monoxide and of surplus air, that analysis of the gaseous products of combustion is desirable, and for those purposes it is invaluable.

In addition to the continuous analysis, carried along all day and all night, in duplicate, for greater assurance of accuracy, samples of the gases drawn off at the same time were stored in bottles properly labeled, for subsequent repetition of the analysis in case verification appeared to be desirable. Such samples should be stored over glycerine, on account of the absorption of CO_2 by water; and on the same account the glycerine should be as nearly as possible anhydrous.

A very small steam or electric pump, with a plunger about 0.25 inch diameter, and stroke 0.5, or 0.75 inches, driven at such speed as to give about one bubble of gas per second at each set of Geissler bulbs, may be conveniently substituted for a siphon, to regulate the flow of the gases; and a short bit of broken thermometer tube, of small caliber, inserted in the line of flexible tube, helps to give a more uniform flow.

It is better to use Geissler bulbs of large size, and to deal with as large quantities of gas as can be conveniently managed; and on this account the balance—which cannot be too nice—should be of large size, adapted to weigh, without undue strain, 200 grammes, nearly 3,100 grains, say 7 oz. avoirdupois. With these precautions, proper care, adequate skill and *perfect integrity*, duplicate and repeated analyses will be found to agree very closely. Differences will appear, under the high magnifying power of decimals of one per

cent., but these differences will usually be very small. Such quantities as 0.12, or 0.08 of one per cent. (.0012, or .0008), appear small; but when they are found repeating themselves under like conditions, the results appear to be entitled to much confidence. Subsequent experience, indeed, has led Mr. Prentiss to the opinion that neglect to surround the calcium chloride tube with crushed ice may have permitted a little vapor of water to pass with the imperfectly desiccated gases into the potash bulbs, and so to increase very slightly the small quantity of CO. Reference has already been made to persistent attempts to produce carbon monoxide in quantities unusually large

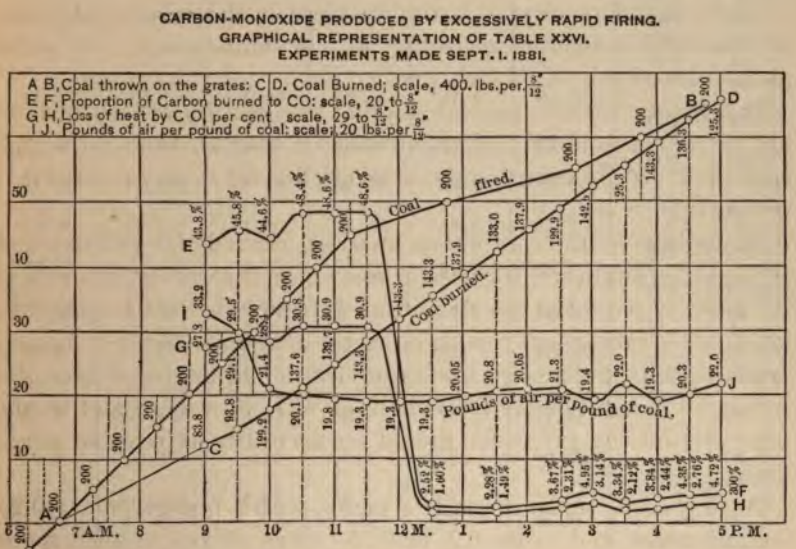

FIG. 19.

and to special analyses of the chimney gases during short periods, at regular intervals, under certain conditions of the fire, to determine the quantity of CO so produced. Such experiments were made during the entire working day, September 1, 1881. A succinct statement of the results of these experiments will be found in Table XXVI., and all the figures of this table, except those in columns 3 and 4, are graphically represented on the diagram, Figure 19. Both table and diagram are so plain as to require little explanation. They will be readily understood by any one who will give them a few minutes careful attention. Beginning at the lower left-hand corner of the diagram, it will be seen that a charge of 200 pounds of

TABLE XXVI.

CARBON MONOXIDE PRODUCED BY EXCESSIVELY RAPID FIRING.

A.M. TIME. H. M.	Pounds of coal thrown on the grate. Lbs.	Carbon dioxide in chimney gases. Per centum, CO_2.	Carbon monoxide in chimney gases. Per centum, CO.	Ratio of carbon in CO to total carbon. Per centum.	Pounds of air per pound of coal. Lbs.	Pounds of coal burned each half hour. Lbs.	Ratio of loss by CO to full power of coal. Per centum.
1	2	3	4	5	6	7	8
6:15	200						
6:45	200						
7:15	200						
7:45	200						
8:15	200						
8:45	200						
9:		5.12	2.54	43.80	33.2	83.81	27.84
9:15	200						
9:30		5.55	2.99	45.85	29.5	93.75	29.14
9:45	200						
10:		7.79	3.99	44.63	21.4	129.24	28.37
10:15	200						
10:30		7.70	4.61	48.47	20.1	157.60	30.81
10:45	200						
11:		7.82	4.70	48.57	19.8	139.68	30.88
11:15	200						
11:30		8.01	4.81	48.55	19.3	143.30	30.86
12 M.					19.3	143.30	
12:30		15.21	.25	2.52	19.3	143.30	1.60
12:45	200						
1:					20.65	137.94	
1:30		14.11	.21	2.28	20.8	132.96	1.49
2:					21.05	137.94	
2:30		13.62	.33	3.67	21.3	129.85	2.31
2:45	200						
3:		14.50	.48	4.95	19.4	142.56	3.14
3:30		13 18	.29	3.34	22.	125.34	2.12
3:45	200						
4:		14.96	.38	3.84	19.3	143.30	2.44
4:30		14.18	.41	4.35	20.3	136.25	2.76
4:45	200						
5:		13.01	.41	4.72	22.	125.34	3.00
Mean quantity of air.....					21.653		
Mean of all but two first.....					20.36		
Mean ratio of loss ; first 6, *per cent*.....							29.65
Mean ratio of loss ; last 8, *per cent*.....							2.36

coal—anthracite, egg size—was thrown on the fire-grates, upon a banked fire, started up at 6:15 A.M., and a like charge every 30 minutes thereafter until 11:15 A.M.

After an interval of 1 hour and 30 minutes, at 12:45 P.M., 200

pounds was again thrown on the fire; and again at 2:45, 3:45, and 4:45 at intervals, respectively, of 2 hours, 1 hour and 1 hour. Thus, the firing was, for 5 hours 15 minutes, up to 11:15 A.M., at the uniform rate of 400 pounds per hour, equal to 16 pounds per square foot of fire-grate per hour; and after 11:15 A.M., it was at the mean rate of 145.45 pounds per hour, equal to 5.82 pounds per square foot of fire-grate per hour—only 36 per cent. as much.

Beginning at 9 A.M., samples of gas were obtained and analyzed half-hourly, except at the hours of 12 M., and 1 and 2 P.M., when there was, in each case, an interval of an hour. The half-hourly samples were taken during the whole preceding half hour, and the hourly samples during the whole preceding hour, so that the whole day from half-past eight is covered by the analyses of the gases. The ratio, per cent. of CO_2 and of CO to the total quantity of dry flue gases, is given in columns 3 and 4 of Table XXVI., but these figures are not represented on the diagram, Fig. 19.

In column 5 of the table, represented by line EF of the diagram, the proportion of coal burned to CO is given as a *per centum* of all the carbon in the coal. During 2 hours and 30 minutes, 9:00 to 11:30 A.M., the mean is 46.64 per cent., showing that only 53.36 per cent. was completely burned to CO_2. The number of pounds of atmospheric air found in the flue gases for each pound of coal consumed, given in column 6 of the table, and represented by line IJ of the diagram, was rather small, and nearly uniform; the mean for 8 hours being 21.65 pounds, and for 7 hours, after 10:00 A.M., only 20.36 pounds. The ratio of heat lost by CO to the full heating power of the coal is given in column 8 of the table, and is represented by line GH of the diagram.

This loss is obviously less than the whole quantity of CO produced, because *some* heat is evolved in burning carbon to CO.

While carbon burned to CO_2 produces, per pound, 14,544 British thermal units, the same quantity burned to CO produces but 4,451 of the same heat units. The loss (= 14544 − 4451 = 10093 British thermal units) is about 69.39 per cent., and the numbers in column 8 would be 69.39 per cent. of those opposite in column 5, if carbon were the only combustible in the coal, as it is in coke. But there is, in fact, an appreciable quantity of hydrogen in this coal, probably united with carbon as some one or more of the hydrocarbons, useful as fuel, and this hydrogen loses nothing in consequence of the formation of CO; and the effect of this circumstance is to reduce the ratio of the loss by CO to about 63.5 per cent.

The losses to be accounted for, to be guarded against, and to be reduced to a minimum, in the combustion of coal in the furnaces of steam boilers (aside from external radiation from boiler and brickwork), are all embraced as classified under the five heads, *B*, *C*, *D*, *E* and *F*, in the following list.

A = Pounds off flue gases per pound of coal.
A—a = Pounds of atmospheric air per pound of coal.
B = Heat carried off by flue gases (exclusive of vapor contained in these gases).
C = Heat lost by water in the coal.
D = Heat lost by vapor in the air.
E = Heat lost by CO in the flue gases.
F = Heat lost by hydrogen in the flue gases.
a = Number of pounds of carbon in 100 pounds of coal.
b = Number of pounds of hydrogen in 100 pounds of coal,
c = Number of pounds of water in 100 pounds of coal.
d = Number of pounds of ash in 100 pounds of coal.
e = Number of pounds of CO_2 in 100 pounds of flue gases.
f = Number of pounds of CO in 100 pounds of flue gases.
g = Number of pounds of hydrogen in 100 pounds of flue-gases.
h = Proportion of vapor in atmospheric air.
k = Number of British thermal units developed by 1 pound of coal perfectly burned; ascertained by analysis.
n = Temperature of external air; degrees F.
p = Temperature of escaping gases; in smoke-box, with natural draft, or in blower, with the warm-blast apparatus.

To compute the number of pounds of dry flue gases, per pound of coal consumed:

$$A = \frac{a}{.27273e + .42857f} \qquad (1)$$

That is:—Divide the number of pounds of carbon found by analysis in 100 pounds of coal (*a*), by the sum of $\frac{3}{11} = .27273$ of the CO_2, and $\frac{3}{7} = .42857$ of the CO, found by analysis in the flue gases. The quotient will be the number of pounds of dry flue gases per pound of coal consumed.

EXAMPLE.

We find, for instance, that during the week I, ending May 20, 1882, the mean number of pounds of CO_2 in 100 pounds of flue

gases (days), was 12.27; and of CO, 0.18 pounds; and that the number of pounds of carbon in 100 pounds of coal was 82.92.

Then, $$\frac{3 \times 12.27}{11} = 3.342727$$

and $$\frac{3 \times 0.18}{7} = \underline{0.077143}$$

$$.27273e + .42857f = 3.419870$$

and $$\frac{82.92}{3.41987} = 24.2 = A.$$

$A - a = 24.2 - .8292 = 23.37$ = the number of pounds of atmospheric air in flue gases per pound of coal consumed.

To find the heat carried off by the flue gases (exclusive of vapor contained in these gases), in terms of the full heating power of the coal.

$$B = \frac{A \times .238 \times (p - n)}{k} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

That is, multiply the number of pounds of flue gases per pound of coal consumed, by .238, which is the mean specific heat of the mixed flue gases; and this product by the difference in temperature in degrees Fahrenheit between the external air and the escaping gases—at the smoke-box, with natural draft, or, at the blower, with the warm-blast apparatus; and divide this second product by the number of British thermal units expressing the full heating power of the coal.

EXAMPLE.

$A = 24.2$; $p = 164°$; $n = 49°$; $p - n = 115°$; $k = 13139$.

Then: $$\frac{24.2 \times .238 \times 115}{13139} = .0504 = B = 5.04\%.$$

To find the heat lost by water in the coal, in terms of the full heating power of the coal.

$$C = \frac{(c + 9b) \times (1076 - n + .48p)}{100k} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

That is, to the number of pounds of water in 100 pounds of coal, add 9 times the number of pounds of hydrogen in 100 pounds of coal, and multiply the sum by the number 1076 *diminished* by the

number of degrees F. expressing the temperature of the external air, and increased by 0.48 times the number of degrees F. expressing the temperature of the escaping flue gases—at the smoke-box, with natural draft, or at the blower, with the warm-blast apparatus; and divide the product by 100 times the number of British thermal units expressing the full heating power of the coal.

The quotient will be the loss by water in the coal, the quantity sought.

EXAMPLE.

Let $c = 2.39$; $b = 1.80$; $n = 49°$ F.; $p = 164°$; 0.48 = specific heat of steam; $.48p = 79$, and $100k = 1313900$. Then:

$$C = \frac{[2.39 + (9 \times 1.80)] = 18.59 \times (1076 - 49 + 79 = 1106)}{1313900} =$$

$.0156 = 1.56\%$.

To find the loss of heat by vapor in the air, in terms of the full heating power of the coal expressed in British thermal units:

$$D = \frac{(A - \frac{a}{100}) \times h \times .48\,(p - n)}{k} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

That is, from the number of pounds of flue gases per pound of coal consumed, subtract one one-hundredth part of the number of pounds of carbon in 100 pounds of coal; and multiply this difference by the proportion of vapor in the air as ascertained by the hygrometer, and by 0.48 times the difference between the number of degrees F. expressing the temperature of the escaping flue gases (at smoke-box, or blower, as the case may be), and the number of degrees F. expressing the temperature of the external air; then divide the continued product by the number of British thermal units expressing the full heating power of the coal. The quotient will be the loss of heat by vapor in the air, in terms of the full heating power of the coal.

EXAMPLE.

Let $A = 24.2$; $a = 82.92$ $\therefore \frac{a}{100} = .8292$; $h = 1.80\%$; $p = 164°$, $n = 49°$, $p - n = 115°$ F. and $k = 13139$. Then:

$$D = \frac{(24.2 - .8292) \times .018 \times .48 \times 115}{13139} = .0018 = 0.18\%.$$

To find the heat lost by carbon monoxide in the flue gases, in terms of the full heating power of the coal expressed in British thermal units.

$$E = \frac{\frac{3}{7}f \times 101a}{(\frac{3}{11}e + \frac{3}{7}f) \times k} = \frac{.42857f \times 101a}{(.27273e + .42857f) \times k} \quad . \quad . \quad (5)$$

That is, multiply three-sevenths ($\frac{3}{7} = .42857$) of the number of pounds of CO found by analysis in 100 pounds of flue gases, by 101* times the number of pounds of carbon found by analysis in 100 pounds of coal; and divide this product by the continued product of the number of British thermal units expressing the full heating power of the coal, multiplied by three-elevenths of the CO_2 and by three-sevenths of the CO, in pounds found by analysis in 100 pounds of flue gases. The quotient will be the loss of heat caused by the CO in the flue gases, in terms of the full heating power of the coal expressed in British thermal units.

EXAMPLE.

Let $f = 0.18\%$; $a = 82.92\%$; $e = 12.27\%$, and $k = 13139$. Then:

$$E = \frac{(\frac{3}{7} \times .18) \times (82.92 \times 101)}{[(\frac{3}{11} \times 12.27) + (\frac{3}{7} \times .18)] \times 13139} = .0144 = 1.44\%.$$

To find the heat lost by hydrogen in the flue gases, in terms of the full heating power of the coal, expressed in British thermal units.

$$F = \frac{A \times g \times 620.32}{k} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

That is, multiply the number of pounds of flue gases per pound of coal consumed by the number of pounds of hydrogen found by analysis in 100 pounds of flue gases, and by 620.32 (= one one-hundredth part of the number of B. t. u. expressing the full heating power of one pound of hydrogen); and divide the product by the number of British thermal units expressing the full heating power of one pound of the coal as determined by analysis. The quotient will be the loss by unburned hydrogen in the flue gases, in terms of the full heating power of the coal, expressed in British thermal units.

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*101, put for $\frac{10093}{100} = 100.93$; the sum 10093 being 14544 − 4451, see p. 121.

EXAMPLE.

Let $A = 24.2$; $g = 0$; $k = 13139$. Then,

$$F = \frac{24.2 \times 0 \times 620.32}{13139} = 0.$$

No hydrogen has ever been detected in the flue gases, and it seems little likely that any ever escapes from the furnace unburned. Some hydrocarbons, in natural gas, deposit a portion of their carbon in a solid mass behind the bridge wall, especially if introduced into the furnace at too high a temperature; but it is probable that all the free hydrogen present, and all which is combined with carbon, that is, all that is not already burned to water, is so burned in any furnace fire. If, however, any hydrogen should ever be found in the flue gases, its quantity inserted in place of 0 in the above example, will bring out the resulting loss of heat. The sum of the losses *B*, *C*, *D* and *E*, is as follows:

B, loss of heat carried off by the dry flue gases	5.04
C, loss of heat by water in coal	1.55
D, loss of heat by vapor in the air	0.18
E, loss of heat by carbon monoxide	1.44
Total losses at the chimney, per cent	8.21
Add to this the loss by radiation from boiler and brick-work; a quantity varying with the temperature of the external air and with the conditions of each case, but in this case	4.00
Total sum of losses, per cent	12.21
Efficiency of boiler, per cent	87.79
	100.00

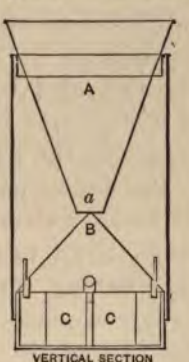
Various small savings can be made in ways already pointed out, which, in the aggregate, may be brought up to the 2.21 per cent. required in order to make the net efficiency 90 per cent. There is still five per cent. of the heat carried off by the flue gases at the moderate temperature of 164° F., only 115° F. above the temperature of the external air.

Part of this may sometimes be saved by warming water after the gases leave the abstractor, and possibly a little may be saved by improvements in the abstractor itself.

But according to present appearances 90 per cent. is about the maximum efficiency attainable by the best possible boiler with warm-blast apparatus, and *that* should be steadily aimed at and pretty nearly attained.

Ashes and Residue.—All ashes and residue withdrawn from

the furnace and ash-pit during each weekly experiment were kept together under cover, until the fire was drawn at the end of the week's work, at midday on Saturday. The fire was allowed to burn pretty low on Saturday; still, as steam was kept up, there was some partially burned coal on the grates when the fire was drawn, and some water was used to quench this coal; but only enough to cool it by evaporation below the point of ignition, so that the ashes and residue, when cold, might be considered to be as dry as the hygrometric state of the air would permit. After division, as has been already said, into five grades, namely (*a*), unburned coal (a small quantity); (*b*), clinker, partly vitreous; (*c*), coarse residue, which would not pass through a screen with hexagonal meshes five-eighths of an inch in short diameter; (*d*), finer residue, passing through said hexagonal meshes, but not passing through a screen with three meshes to an inch each way; and (*e*), ashes which passed through said screen; each grade was weighed by itself, kept separate, and sampled for analysis. The first grade (*a*) was pulverized and sampled in the same manner as the week's coal. The second grade (*b*), clinker, was sampled, by taking a part of almost every lump, making as fair a selection as possible. This grade, which sometimes reached 500 pounds in a week —more than one-fifth of the whole quantity of ashes and residue—was nearly barren of carbon, while the first grade, although small in quantity, was little inferior in carbon to fresh coal.



ORE SAMPLER, FOR OBTAINING SAMPLES OF ASHES AND RESIDUE.

FIG. 20.

The third grade (*c*), the fourth grade (*d*), and the fifth grade (*e*), were sampled by passing them twice in succession through an ore-sampler, shown in Fig. 20. Placed in the conical hopper A, they passed though its open end (*a*), concentrically upon the apex of the right cone B, which distributed them evenly on all sides in a sheet, growing gradually thinner toward its base, near which were placed four tubes, one inch in inside diameter, equidistant in a circle forty inches in circumference, so that each tube was equal in diameter to one-tenth of the quadrant in which it was set.

Of each tube, the side facing the center of the cone and above its surface, was cut away so as to present an open mouth, one inch wide, towards the descending sheet of ashes or cinders, one-tenth of which they received and conducted into the quadrant-shaped cups beneath them in the base of the sampler.

When these cups were full, or when all the ashes or cinders of any grade had been passed through the sampler, the cups were taken out, emptied, and replaced in position; and their contents were again passed through the sampler. By this process, supplemented by a small correction (found by weighing the whole quantity, and the quantity delivered each time into the cups), for any variation in the actual dimensions of the sampler from the exact one-tenth contemplated, a known proportion, about one one-hundreth part of each grade of ash and cinders was obtained, of presumably average quality. Each sample so obtained was then pulverized, and a smaller sample obtained by subdivision in the manner usual in treating ores, was finally bottled, labeled, and put aside for analysis in its turn. The fifth grade (*e*) was, after sampling, again subdivided by passing its finer portion through a sieve of brass wire-cloth of forty meshes to an inch each way. The portion which passed through this sieve, which was much the larger portion, was almost wholly incombustible ash—only about 5 per cent. of it being carbon, while the portion remaining on the sieve, although small in quantity, was almost wholly pure coal, apparently resulting from decrepitation. The weight of each grade being known, and the proportion of carbon in each being ascertained by analysis, it of course follows that the total quantity of carbon in ashes and residue becomes known.

It is probably a safe assumption that no combustible save carbon remains, since volatile hydrocarbons must be either burned to CO_2 and water, or driven off by the heat of the fire.

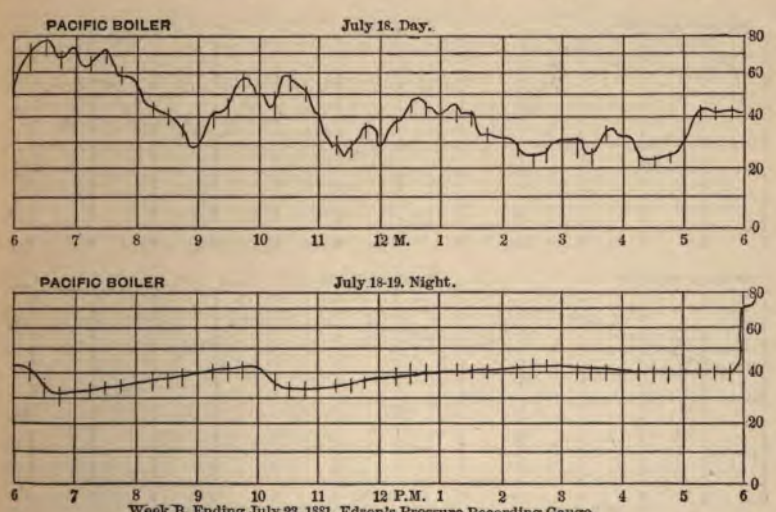
Results finally obtained in the manner above described may be checked by a method much easier, and little less accurate, even in theory, while its simplicity eliminates an accumulation of errors of observation, and makes it, in practice, quite as accurate.

This second method is as follows:

The analysis of the coal thrown on the fire-grates during the week gives the proportion of ash it contains, and this proportion applied to the weight of the coal consumed during the week, after deducting the weight of the unburned coal picked out of the ashes and residue [grade (*a*)], gives the quantity of "ash" proper, in the

week's ashes, cinders, and clinkers of all grades (*b*), (*c*), (*d*), and (*e*). It follows that the excess of the combined weight of ashes and residue of these four grades, over the weight of ash as determined by analysis of the coal, is equal, or nearly equal to the quantity of carbon contained in the ashes and residue of these four grades. It would be exactly equal if all the unburned coal could be picked out; but this can hardly ever be the case, since no inconsiderable quantity goes through the grates in particles too fine to be picked out, and can be segregated only by subdividing grade (*e*), after pulverization, by means of a fine sieve, as above described. In treating a coal which decrepitates very badly, it may be necessary to sample and analyze the ashes and residue, as herein described. Such is the Rhode Island coal, large lumps of which sometimes crumble to fine black sand and sift through a thick fire to the ash-pit, with startling suddenness, without becoming too hot to be held in the hand. But in the use of most, perhaps all, of the Pennsylvania anthracites, the second and simpler mode of procedure I have described will be found sufficiently accurate; and this was the method pursued in the later portion of our work.

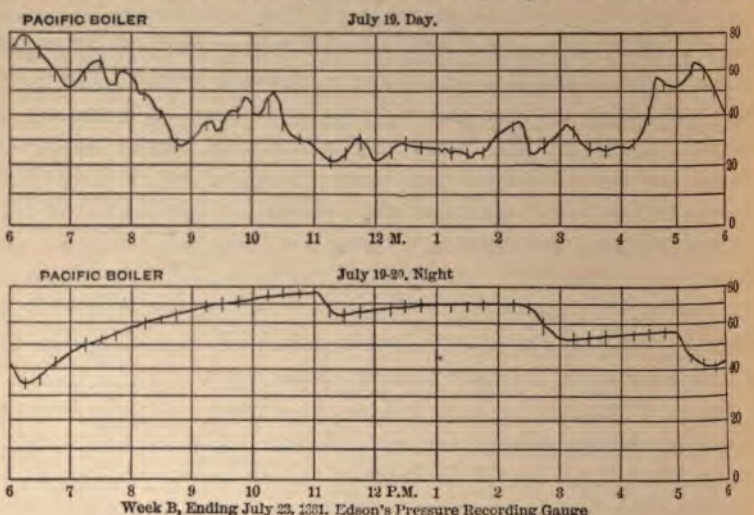
Boiler Pressure by Steam Gauge.—One of Edson's Pressure Recording Gauges was connected with the boiler, and kept in operation throughout the whole duration of the trials. A set of the diagrams from this gauge running through the days and nights of the week ending July 23, 1881 (week B), is given in Fig. 21*a*,



Week B, Ending July 23, 1881, Edson's Pressure Recording Gauge

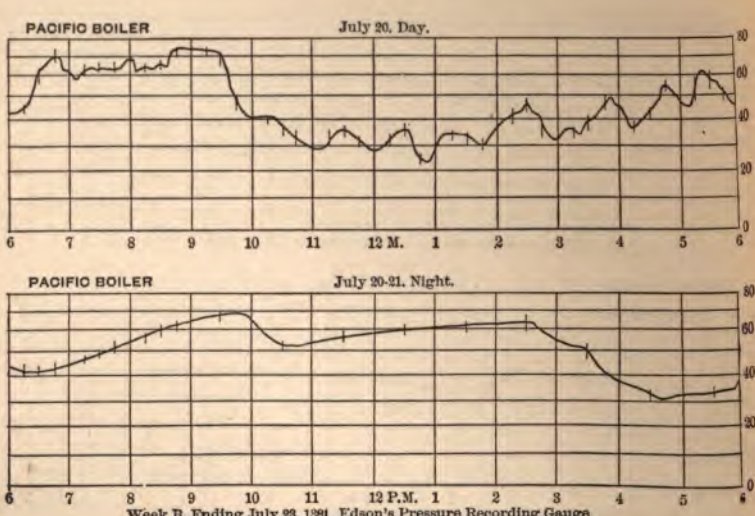
Fig. 21*a*.

b, *c*, *d*, *e*, and *f*, reduced by photography to two-thirds of the size of the diagrams. The upper diagram on each set exhibits the pressures during the day—6 A.M. to 6 P.M., except on Saturday, when the day closed at 12 M. They show very clearly the extremely unequal demand for steam, but very inadequately, for two reasons:—*first*, because the fire was urged and evaporation was accelerated whenever steam pressure was rapidly drawn down, and in



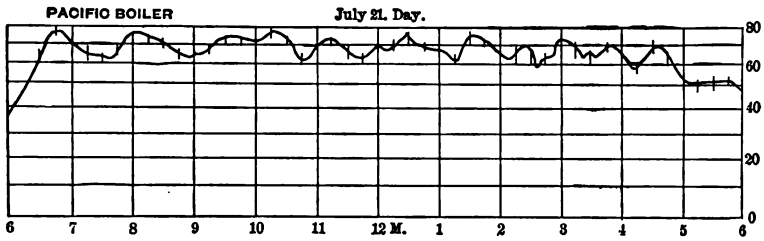
Week B, Ending July 23, 1881. Edson's Pressure Recording Gauge

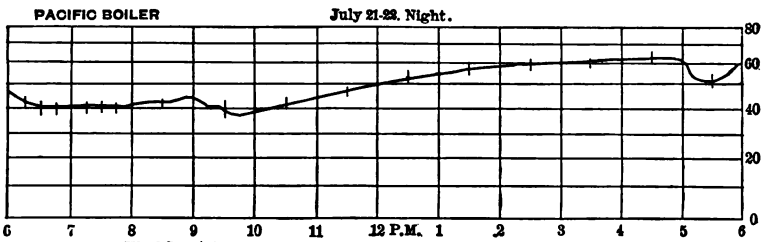
FIG. 21*b*.



Week B, Ending July 23, 1881 Edson's Pressure Recording Gauge

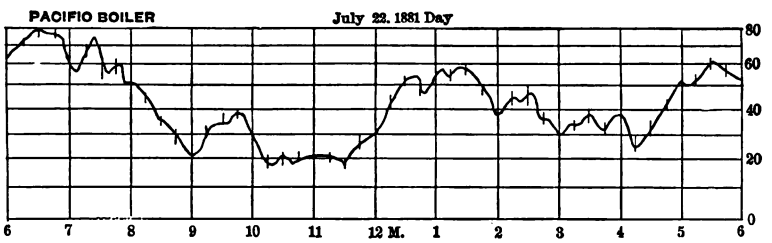
FIG. 21*c*.

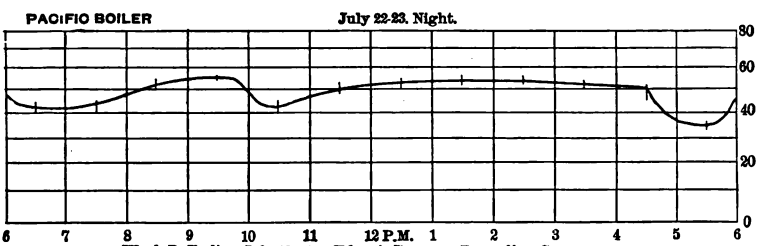




Week B, Ending July 23. 1881. Edson's Pressure Recording Gauge

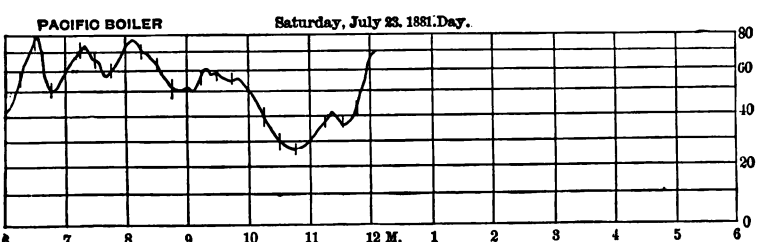
FIG. 21*d*.





Week B, Ending July 23. 1881. Edson's Pressure Recording Gauge

FIG. 21*e*.



Week B, Ending July 23. 1881. Edson's Pressure Recording Gauge

FIG. 21*f*.

some degree checked when it rose; and *second*, on account of the smaller scale on which this gauge records pressures in the upper portion of its register, the 10 lbs., 70 to 80, occupying only half as much space as the lower 10 lbs., above 0. The effect of this is to mask the irregularities, in some degree, making them appear much less than if the scale were uniform throughout.

The Edson gauge is excellent for the purpose of recording the general state of the pressure; but its indications are not sufficiently accurate for numerical calculation, if for no other reason, on account of the small scale on which it works.

It was therefore necessary to take readings of an accurate pressure gauge at stated intervals, as accurately spaced in time as possible.

Such readings were taken every quarter of an hour during the day, and part of the time by night also; but the greater uniformity at night led us, soon, to take readings at the hours and half-hours only. The gauge was a ten-inch Bourdon test gauge, made by the American Steam Gauge Company, which had never before been used except for comparison with other gauges. It had been compared many times with a mercury column, with which it agreed quite closely, and had not been used after having been so tested, until it was used in these experiments.

It was connected with the boiler by a branch pipe from the pipe leading to the Edson gauge, and as the pressure was shut off from the test gauge except when a reading was to be taken for record, a slight reduction of pressure took place at the Edson gauge whenever the stop-cock of the test gauge was opened, producing by the downward motion of the marking pencil, and a little recoil on its rising at the close, a short mark crossing the trace of the Edson recording gauge, which indicates the moment of the reading, and the point in the trace with which the reading is to be compared. A mean was taken of the readings of the test gauge for each day, and for each night, and a general mean for each week, of the days and also of the nights. It will be observed that the diagrams, Fig. 180 *a*, *b*, etc., are reversed in direction from the original diagrams, which read from right to left. This is merely for convenience of reading in the ordinary manner, from left to right. I have not thought it worth while to reproduce here these diagrams for more than a single week, since these fairly represent them all in general character.

CAPACITY OF BOILER AT VARIOUS HEIGHTS OF WATER LINE AND AT VARIOUS PRESSURES.—A scale, graduated to inches and tenths of an inch, was attached to each glass water gauge in such a manner that the surface of the water in the glass tube could be readily referred to it, and readings of this gauge were recorded every quarter of an hour. It was practically impossible to maintain a uniform water level, and it was found to be inconvenient to bring the water at the close of an experiment, at noon on Saturday, to agree exactly with that at starting, on Monday morning. It was therefore necessary to ascertain the true difference in quantity due to any observed difference in height of surface; and convenience required that this should be ascertainable by inspection of a table. The subjoined table, Table XXVII., was therefore constructed, showing the capacity of the boiler expressed in pounds avoirdupois of water at the zero of the scale, and at each inch of height above that zero, with differences for ascertaining by interpolation the quantity for parts of inches. The height, in inches of the water surface above the zero of the scale, is given in the left-hand column of the table, which is in two parts. But the weight of a given volume of water varies with its temperature, which corresponds with the absolute steam pressure. The table is, therefore, computed for 17 different pressures, from 0 = one atmosphere = 14.7 pounds per square inch absolute, up to 80 pounds steam-gauge pressure = 94.7 pounds absolute, at intervals of 5 pounds, as indicated by the figures at the head of the columns, which are steam-gauge pressures; with columns of differences for ascertaining by interpolation the quantity of water at intermediate pressures. The zero of the scale is near the lower end of the tube, and about 3.08 inches above the top of the upper row of flues, and 9.33 inches above the center of the shell.

EXAMPLE OF THE USE OF THE TABLE.

In the experiment for the week ending May 20, 1882, at 6 h. 32 m. A.M. on Monday, May 15, the reading at the scale of the glass water gauge was 5.3 inches; pressure of steam by steam gauge, 15 pounds. At 12 M. on Saturday, May 20, water stood at 3.0 inches, steam at 50 pounds.

Then, by consulting the table, we find in the column headed 15, opposite the height of 5 inches, water in boiler	13,546 lbs.
Difference for 1 inch = 424 lbs.	
And 424 × .3 =	127 lbs.
Pounds of water at starting	13,673 lbs.
The column headed 50, opposite the height 3 inches, water in boiler	12,404 lbs.
Number of pounds less at the end of the experiment than at its beginning	1,269 lbs.
Number of pounds fed into the boiler during the experiment	156,214 lbs.
Number of pounds of water evaporated during the experiment	157,483 lbs.

Since the two boilers are alike, this table applies equally well to both.

Radiation from Brick-work.—An attempt was made to measure the quantity of heat lost by radiation from the brick-work, which, although unsatisfactory, yet seems to possess some interest, and will be briefly noticed.

The Apparatus.—Two tin-plate vessels were provided, each twelve inches square and one inch thick, closed on all sides. On one side, near the corners, there were two rings by which the vessels could be hung up upon nails driven into the brick-work. In the upper edge, when so suspended, there was a tubular orifice, about 0.75 inch in diameter, slightly tapering, for convenient insertion of a cork. Through the cork two small glass tubes were inserted; one, for inflowing water, extending down inside nearly to the bottom of the vessel; the other, for outflowing water, extending but slightly through the cork.

Each of these tubes, near the entrance through the cork into the vessel, was provided with a suitable enlargement, bend and orifice for convenient insertion of a thermometer, to show the temperature of inflowing and outflowing water. Water was supplied from a bucket suspended in an elevated position, and received in a bucket on the floor, surrounded by ice, to reduce loss of weight by evaporation. The edges and the back of the vessels were protected from loss of heat by radiation, at least in some degree, by a hood of cotton flannel filled with eider down; and the edges of this hood were drawn slightly over the naked side next the brick-work, by a gathering-string, to cut off circulating air currents which would carry off heat by convection. Finally, the naked side was coated thickly with dry lampblack, for the better absorption of radiant heat.

CAPACITY OF BOILER IN POUNDS OF WATER, FOR EACH INCH IN HEIGHT, FROM 0 TO 10 INCHES, AND FOR EACH 5 POUNDS OF STEAM-GAUGE PRESSURE, FROM 0 TO 80 POUNDS.

IN.	0	D.	5	D.	10	D.	15	D.	20	D.	25	D.	30	D.	35	D.
10	15809	101	15708	80	15628	67	15561	61	15500	50	15450	48	15402	44	15358	42
	386		382		381		379		378		376		376		375	
9	15423	97	15326	79	15247	65	15182	60	15122	48	15074	48	15026	43	14983	41
	398		396		394		392		390		390		388		387	
8	15025	95	14930	77	14853	63	14790	58	14732	48	14684	46	14638	42	14596	40
	412		410		408		406		405		403		402		400	
7	14613	93	14520	75	14445	61	14384	57	14327	46	14281	45	14236	40	14196	39
	420		417		414		414		411		410		408		408	
6	14193	90	14103	72	14031	61	13970	54	13916	45	13871	43	13828	40	13788	38
	431		429		427		424		423		422		421		419	
5	13762	88	13674	70	13604	58	13546	53	13493	44	13449	42	13407	38	13369	37
	446		442		440		438		436		435		433		433	
4	13316	84	13232	68	13164	56	13108	51	13057	43	13014	40	12974	38	12936	35
	449		447		444		443		441		439		438		436	
3	12867	82	12785	65	12720	55	12665	49	12616	41	12575	39	12536	36	12500	34
	457		453		453		449		448		446		445		444	
2	12410	78	12332	65	12267	51	12216	48	12168	39	12129	38	12091	35	12056	33
	464		462		458		457		455		454		452		451	
1	11946	76	11870	61	11809	50	11759	46	11713	38	11675	36	11639	34	11605	31
	470		466		464		462		460		459		458		456	
0	11476	72	11404	59	11345	48	11297	44	11253	37	11216	35	11181	32	11149	31

TABLE XXVII.—*Continued.*

CAPACITY OF BOILER IN POUNDS OF WATER, FOR EACH INCH IN HEIGHT, FROM 0 TO 10 INCHES, AND FOR EACH 5 POUNDS OF STEAM-GAUGE PRESSURE FROM 0 TO 80 POUNDS.

IN.	40	D.	45	D.	50	D.	55	D.	60	D.	65	D.	70	D.	75	D.	80	D.
10	15316	41	15275	35	15240	35	15205	32	15173	29	15144	30	15114	28	15086	28	15058	27
	374		373		371		370		370		369		368		368		367	
9	14942	40	14902	33	14869	34	14835	32	14803	28	14775	29	14746	28	14718	27	14691	26
	386		385		384		384		382		382		381		380		380	
8	14556	39	14517	32	14485	34	14451	30	14421	28	14393	28	14365	27	14338	27	14311	26
	399		398		398		396		396		395		394		394		392	
7	14157	38	14119	32	14087	32	14055	30	14025	27	13998	27	13971	27	13944	25	13919	25
	407		405		404		404		403		402		402		400		400	
6	13750	36	13714	31	13683	32	13651	29	13622	26	13596	27	13569	25	13544	25	13519	25
	418		417		416		415		414		413		412		412		411	
5	13332	35	13297	30	13267	31	13236	28	13208	25	13183	26	13157	25	13132	24	13108	24
	431		430		429		428		427		427		425		425		424	
4	12901	34	12867	29	12838	30	12808	27	12781	25	12756	24	12732	25	12707	23	12684	23
	435		435		434		432		431		430		430		429		428	
3	12466	34	12432	28	12404	28	12376	26	12350	24	12326	24	12302	24	12278	22	12256	22
	443		441		439		439		439		437		437		435		435	
2	12023	32	11991	26	11965	28	11937	26	11911	22	11889	24	11865	22	11843	22	11821	21
	449		448		448		447		445		445		444		443		442	
1	11574	31	11543	26	11517	27	11490	24	11466	22	11444	23	11421	21	11400	21	11379	20
	456		454		453		452		451		450		449		449		448	
0	11118	29	11089	25	11064	26	11038	23	11015	21	10994	22	10972	21	10951	20	10931	19

The method of using this simple apparatus consisted of noting at frequent and regular intervals the temperature of the inflowing and outflowing water, and in ascertaining the quantity of water flowing through each vessel in a known interval of time.

TRIAL OF THE APPARATUS.—On the 10th of August, 1881, both these radiometers were placed, side by side, on the smoke-box cover of the Pacific Boiler—marked, for distinction No. 1 and No. 2—and streams of water, supposed to be nearly alike, were set to flow through them. A first experiment of one hour, 8 h. 45 m. to 9 h. 45 m. A.M., was immediately followed by a second, of 3 h. 30 m.—10 h. 0 m. A.M. to 1 h. 30 m. P.M. Observations of temperatures were noted every 15 minutes. The water was weighed at the close of each experiment. The results are given in Tables XXVIII. and XXIX.

The line marked "B. t. u., total," is obtained by multiplying the number of British thermal units corresponding to the increase of temperature, by the number of pounds of water to which such quantity of heat was imparted, in each case.

TABLE XXVIII.

RADIATION: EXPERIMENT NO. 1.

RADIOMETER NO. 1.		RADIOMETER NO. 2.	
Water heated, lbs.....	8.797	Water heated, lbs.....	15.563
Mean t, initial	78.16°	Mean t, initial	77.32°
Mean t, final	95.40°	Mean t, final	93.10°
Mean increase, deg.....	17.24°	Mean increase, deg	15.78°

TIME.	TEMPERATURE OF WATER.		TIME.	TEMPERATURE OF WATER.	
	Initial. Degrees F.	Final. Degrees F.		Initial. Degrees F.	Final. Degrees F.
8:45	76.8°	98.8°	8:45	76.5°	91.0°
9	77.4°	92.3°	9	76.3°	93.8°
9:15	78.0°	97.9°	9:15	76.9°	93.0°
9:30	78.7°	93.0°	9:30	77.0°	92.0°
9:45	79.9°	95.0°	9:45	79.9°	95.7°
Mean	78.16°	95.4°	Mean	77.32°	93.10°
B. t. u.....	78.1923	95.4642	B. t. u	77.3506	93.1612
B. t. u., increase		17.2719	B. t. u., increase		15.8106
B. t. u., total, 1 hr.....		151.9409	B. t. u., total, 1 hr		246.0604

TABLE XXIX.

RADIATION: EXPERIMENT NO. 2.

RADIOMETER NO. 1.		RADIOMETER NO. 2.	
Water heated, lbs.	13.105	Water heated, lbs.	23.699
Mean t, initial	85.37°	Mean t, initial	79.91°
Mean t, final	109.47°	Mean t, final	109.93°
Mean increase, deg.	24.10°	Mean increase, deg.	30.01°

TIME.	TEMPERATURE OF WATER.		TIME.	TEMPERATURE OF WATER.	
	Initial. Degrees F.	Final. Degrees F.		Initial. Degrees F.	Final. Degrees F.
10	87.8°	105.2°	10	79.0°	100.0°
10:15	75.2°	105.3°	10:15	78.0°	105.0°
10:30	78.7°	101.8°	10:30	78.5°	108.5°
10:45	79.6°	103.0°	10:45	79.0°	111.6°
11	79.5°	104.0°	11	79.0°	114.5°
11:15	80.3°	105.0°	11:15	79.5°	117.0°
11:30	80.7°	105.5°	11:30	77.0°	109.0°
11:45	81.7°	106.0°	11:45	79.5°	109 0°
12	87.8°	109.0°	12	88.3°	112.0°
12:15	90.5°	111.2°	12:15	89.1°	112.5°
12:30	93.1°	114.3°	12:30	77.5°	112.2°
12:45	94.7°	120.2°	12:45	79.0°	107.0°
1	96.0°	119.5°	1	78.2°	108.4°
1:15	96.6°	121.0°	1:15	78.0°	110.2°
1:30	78.4°	111.0°	1:30	79.0°	113.0°
Mean	85.37°	109.47°	Mean	79.91°	110.00°
B. t. u.	85.4157	109.5784	B. t. u.	79.9458	110.1100
B. t. u., increase		24.1627	B. t. u., increase		30.1642
B. t. u., total, 3.5 hrs		316.6522	B. t. u., total, 3.5 hrs		714.8614
B. t. u., per hour		90.4721	B. t. u., per hour		204.2461
B. t. u., Mean, 4.5 hrs.		104.1318	B. t. u., mean, 4.5 hrs.		203.4015

The tables present some striking anomalies, but some coincidences no less striking.

The result obtained from radiometer No. 1, is very much less than that obtained from No. 2—only 62 per cent. as much in the first hour, experiment No. 1; only 44 per cent. in the following 3.5 hours, experiment No. 2; and for 4.5 hours, taking both experiments together, 51 per cent.

There was certainly no corresponding difference in the *radiation* from the two parts of the smoke-box cover, which were only a few inches apart, and almost certainly of equal temperature. The difference here noted in the *apparent* radiation is at once too large and too uniformly persistent to be explained by any errors of ob-

servation. Two explanations suggest themselves, which, singly or in conjunction, may account for it.

First, radiometer No. 1 may not have been so adjusted to the brick-work as entirely to cut off circulation of air, and consequent loss of heat by convection; and *second*, radiometer No. 2 may have been, to some extent, in contact with the smoke-box cover, so as to receive some heat by conduction. The object of these preliminary experiments was to test the accuracy of the radiometers, and the intention was to divide the area of the brick-work into portions of about one square yard, and to apply the radiometers in turn to each and all of these partial areas. The first results were not satisfactory, and circumstances did not permit the prosecution of this inquiry. The date of these experiments, August 10, 1881, falls in the week ending August 13, week E. The coal burned that week was 14,670, pounds of evaporative power equal to the evaporation of 13.64 pounds of water from and at 212° F., and therefore capable of producing:

$$14670 \times 13.64 \times 965.7 = 193235411 \text{ B. t. u.}$$

Loss from imperfect combustion was 1.81 per cent. The loss by radiation from brick-work, for week E., appears to be 1.39 per cent.; but this is a residuum, and is affected by many small errors. It is therefore proper to take the mean for the six weeks, July 16 to August 20, which was 2.81 per cent.

Now, 1.81 per cent. of 193235411 = 3497561, and

subtracting 3497561

we have 189737850 as the number of British thermal units actually produced in week E. Taking 2.81 per cent. of the heat produced = 5331634 British thermal units, going on day and night, say 132 hours per week, we have $\frac{5331634}{132} = 40391$ B. t. u. per hour. The total radiating surface of the Pacific boiler setting was about 1000 square feet, and dividing by this number the quantity of heat radiated per hour, we have, $\frac{40391}{1000} = 40.39$ B. t. u. per square foot per hour. If this be the mean radiation from the whole outside surface of the brick-work, the rate must be much greater directly opposite the fire. If 2.5 times as much, it would be 40.39 × 2.5 = say, 101, about equal to the quantity shown by radiometer No. 1, and about half as much as appears by No. 2. But these experiments were upon the iron cover of the smoke-box, where the

radiation was probably considerably more rapid than from the brick-work, although the internal temperature was low. Inconclusive as were these experiments, the apparatus appears to have elements of usefulness, and may, with patience and care, yield valuable information.

TRANSMISSION OF HEAT THROUGH BRICK-WORK.—All the heat radiated from the surface of the brick-work must of course reach the surface from within by conduction.

For studying the conduction the following provision was made, Round wooden rods, about 1.5 inches in diameter, a little tapering, were laid, horizontally and transversely, in the side wall of warm-blast boiler No. 2, in two rows, respectively 4′ 5″ and 5′ 0″ above the floor, 14 inches apart in each row, those in the upper row being placed centrally over the spaces between those in the lower row. There were 7 in each row, penetrating respectively 4, 8, 12, 16, 20, 24, and 28 inches; the latter, therefore, having only the width of one fire-brick (4.5″) between its extremity and the combustion chamber, about midway between the bridge wall and the pier. On the withdrawal of the rods, holes were left for the insertion of thermometers to the several depths above mentioned.

The position of the deep and shallow holes was reversed in the two rows, so that the 4″ holes in each row were near the 28″ holes in the other. This arrangement will be clearly seen in Fig. 181.

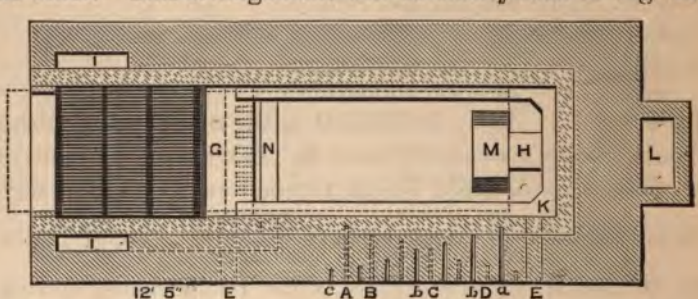


FIG. 22.

HORIZONTAL SECTION OF BRICK-WORK OF WARM-BLAST BOILER; SHOWING THE LOCATION OF HOLES FOR TAKING TEMPERATURES.

Three sets of observations were taken in these holes; the first, during all the working hours of one week, quarter-hourly—Monday morning, September 19, to Saturday noon, September 24, 1881, in the 28-inch hole, A, Fig. 181, in the lower row, located 12′ 5″ from the front end, and 8″ above the level of the lower side of boiler. The observed temperatures are all given in Table XXX., and repre-

TABLE XXX.

TEMPERATURES OF BRICK-WORK, WARM-BLAST BOILER NO. 1, 12′ 5″ FROM FRONT END,—2′ 5″ ABOVE GRATES,—28″ FROM OUTSIDE, 4.5″ FROM INSIDE OF SIDE WALL,—MONDAY, SEPT. 19, 7 h. 30 m. A.M., TO SATURDAY, SEPT. 24, 12 h. 15 m. P.M., 1881. BY MERCURIAL THERMOMETER: QUARTER-HOURLY READINGS. SEE PROFILE, FIG. 183.

TIME.	Monday. 19	Tuesday. 20	Wednesday. 21	Thursday. 22	Friday. 23	Saturday. 24
H. M.	Degrees F.	Degrees F.	Degrees F.	Degrees F.	Degrees F.	Degrees F.
7 A.M.		354	344			390
15		358	344	330	360	392
30	244	360	344	323	360	384
45	240	356	341	323	356	383
8	239	355	340	320	360	385
15	240	358	340	325	360	385
30	240	357	341	327	363	384
45	242	360	341	329	363	386
9	242	362	346	349	363	383
15	246	362	350	350	370	382
30	248	354	344	334	372	383
45	254	358	344	340	374	384
10	256	364	346	340	374	388
15	260	368	346	332	378	384
30	264	368	348	348	382	384
45	268	370	348	350	384	384
11	272	372	348	352	386	386
15	278	372	348	350	386	386
30	270	374	346	354	394	386
45	280	374	348	358	397	386
12 M.	294	376	350	362	399	386
15 P.M.	300	378	352	364	401	386
30	302	378	354	366	403	
45	308	380	354	366	404	
1	312	380	354	366	414	
15	316	382	354	366	415	
30	320	383	357	372	416	
45	323	384	358	373	420	
2	337	386	358	373	421	
15	342	386	358	374	428	
30	347	388	359	375	430	
45	350	390	362	374	434	
3	350	390	362	376	438	
15	358	392	362	374	435	
30	358	394	356	378	436	
45	370	398	354	374	444	
4	372	394	364	374	444	
15	378	398	364	376	450	
30	384	398	364	376	450	
45	384	392	366	376	450	
5	392	394	362	384	452	
15	392	394	364	386	454	
30	394	394	364	388	452	
45	400	394	362	392	452	
6		394	364		452	

sented graphically in Fig. 23 and Fig. 24. In Fig. 23, the several daily profiles would, if all drawn from the same base-line, confuse each other. The 400° line is therefore raised for each succeeding profile, enough to permit all to be clearly seen. The waving lines connect the points observed, of which there were on Monday, 42, on Tuesday and Wednesday, 45 each, on Thursday 43, on Friday 44, and on Saturday 22, making 241 in all.

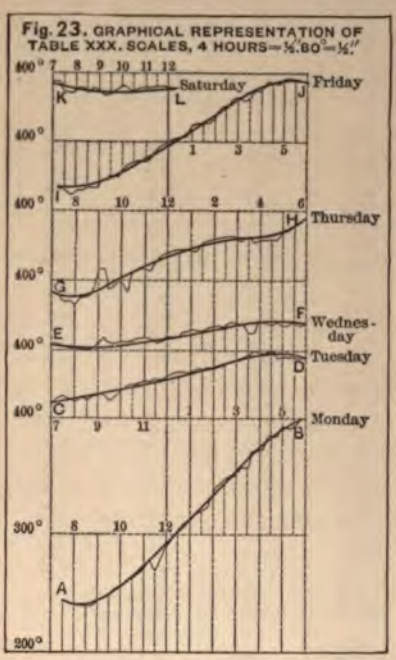
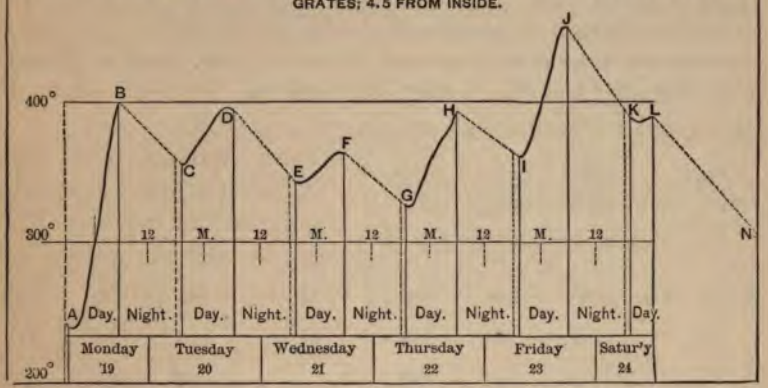


Fig. 23. GRAPHICAL REPRESENTATION OF TABLE XXX. SCALES, 4 HOURS=½", 80°=½".

These waving lines represent, for the most part, if not always, real fluctuations of temperature. Every opening of a fire-door sent a pulse of low temperature through the brickwork, and this was sharply felt so near as 4.5 inches to the source of heat. The smooth curves are intended to represent approximate mean ranges of temperature. On Monday the temperature remained stationary, indeed fell 4° or 5° while the banked fire was opened, and fresh coal put on, but from 8:30 rose sharply, although not quite uniformly, to the close, and reached 400°, a point not again attained until noon of Friday. The effect of light firing and early banking is distinctly seen on Tuesday and Wednesday. On Friday, the fire was driven hard at midday. This was the day on which an experiment was made to ascertain the power consumed in driving the blower, when the speed of the engine was 191 revolutions per minute, and that of the blower, 232, resulting in a rate of combustion equal to 16.63 pounds of coal per square foot of grate per hour. Fig. 24 shows the same mean curves on the same vertical scale, combined with a horizontal scale one-sixth as large, and the intervening nights, in which the temperature is represented by dotted lines, connecting the last observation of each day with the first of the day following. From Saturday noon, when the fire was drawn, the dotted line is seen sloping away to reach some low point on the following Monday morning; but the form of this

Fig. 24.

GRAPHICAL REPRESENTATION OF TABLE XXX. VERTICAL SCALE AS IN FIG. 182, 80° TO $\frac{8}{12}$"
HORIZONTAL SCALE, 24 HOURS TO $\frac{8}{12}$" INCH. IN BRICK-WORK 12'11" FROM FRONT END, 2'5" ABOVE GRATES; 4.5" FROM INSIDE.



curve and of the night curves, is conjectural, no night observations having been taken.

Table XXXI. presents a record of 24 observations at each of 3 holes, severally 8″, 16′, and 24″ in depth, and therefore 20.5″, 16.5″, and 8.5″ from the fire, taken on Monday, February 13, 1882. In Fig. 25, these observations are arranged in the form of three profiles upon the interval of time, 5 h. 45 m. as a base. The assumed means, represented by the full, smooth curves, are here a little more arbitrary; but this is, as will be seen, of no importance.

Fig. 25.

GRAPHICAL REPRESENTATION OF TABLE XXXI. FEBRUARY 13, 1882 TEMPERATURES IN BRICK-WORK.

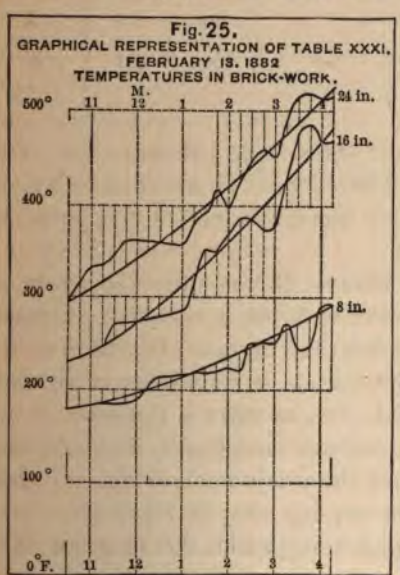


Fig. 26.

QUARTER-HOURLY MEAN TRANSVERSE TEMPERATURES IN BRICK-WORK: FROM TABLE XXXI. FEB. 13, 1882.

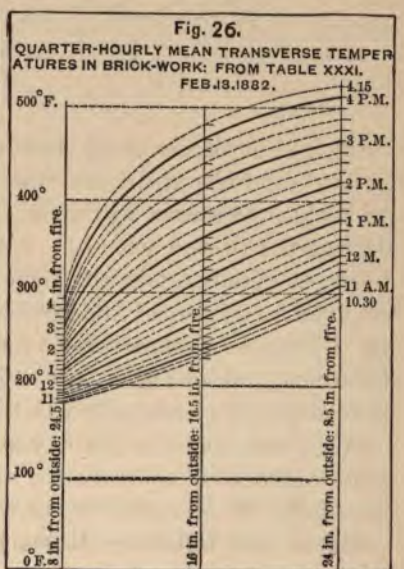


TABLE XXXI.

TEMPERATURE OF BRICK-WORK OF WARM-BLAST BOILER SETTING NO. 1, AT VARIOUS DEPTHS, NAMELY, 8 INCHES, 16 INCHES AND 24 INCHES FROM THE OUTER SURFACE: 10 h. 30 m. A.M. TO 4 h. 15 m. P.M., MONDAY, FEBRUARY 13, 1882. SEE FIG. 184. 5 FEET ABOVE FLOOR.

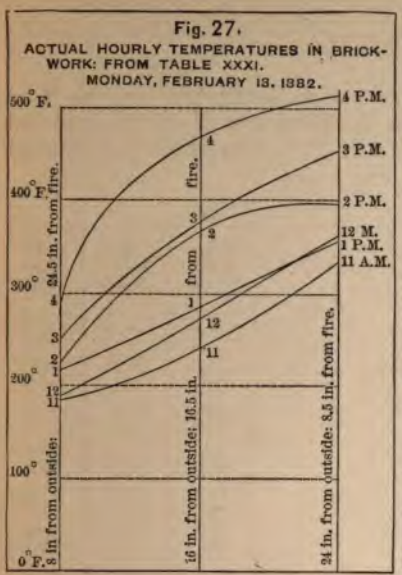
TIME. H. M.	8 inches from outside. Deg. F.	16 inches from outside. Deg. F.	24 inches from outside. Deg. F.	TIME. H. M.	8 inches from outside. Deg. F.	16 inches from outside. Deg. F.	24 inches from outside. Deg. F.
10 30 A.M.	180	230	294	1 30 P.M.	220	352	392
45	182	232	316	45	220	348	415
11	184	242	332	2	224	368	397
15	186	246	334	15	222	385	425
30	186	272	344	30	252	384	446
45	186	273	361	45	252	374	459
12 M.	190	274	361	3	252	376	453
15 P.M.	203	276	360	15	274	431	490
30	215	279	359	30	244	480	513
45	215	282	357	45	248	487	519
1	217	286	356	4	290	468	513
15	220	311	381	15	293	469	515

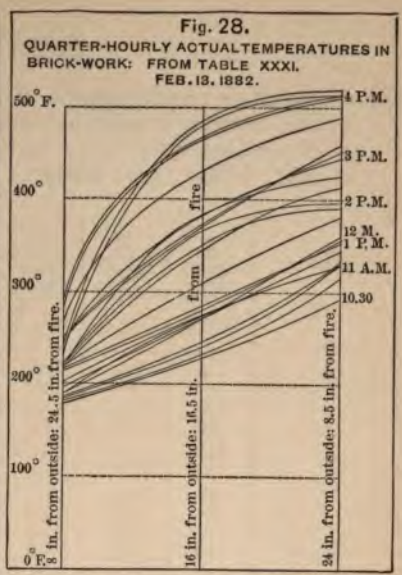
Fig. 26 represents these assumed mean temperatures as a succession of profiles upon the thickness of brick-work they embrace (16 inches), as a base, by full lines at the hours, and dotted lines at the quarters of an hour.

Fig. 27 represents in the same manner as the preceding figure, the hourly profiles, by the temperatures actually observed; agreeing in general configuration with the last figure, but differing in detail, and presenting a little less range in consequence of the omission of two lines before 11, and one line after 4 o'clock.

Fig. 28 is similar to the two preceding, except that here all the quarter-hourly lines are drawn from the actual observations, and embody all the irregularities of the waving lines of Fig. 25.

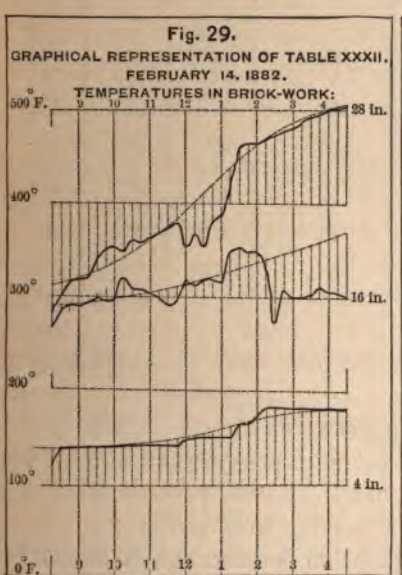
This table is noticeable for the high temperature found, especially





in the 16-inch hole, and notably in the last five observations—431 to 487 degrees.

Table XXXII. embraces 34 sets of observations in 3 holes severally, 4″, 16″, and 28″ deep. The 16″ hole is not identical with the 16″ hole of Table XXXI., but is only 7″ from it horizontally, and



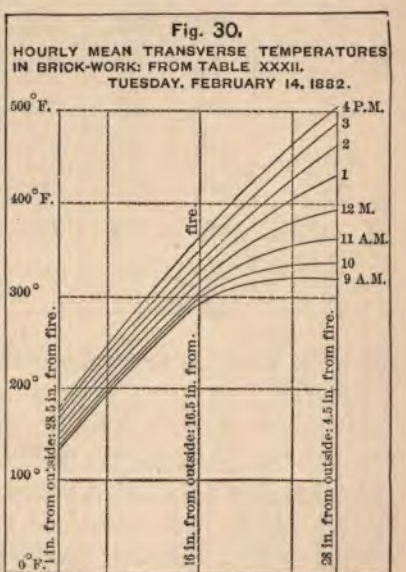


TABLE XXXII.

TEMPERATURE OF BRICK-WORK OF WARM-BLAST BOILER SETTING NO. 1, AT VARIOUS DEPTHS, NAMELY, 4 INCHES, 16 INCHES, AND 28 INCHES FROM THE OUTER SURFACE: 8 h. 15 m. A.M. TO 4 h. 30 m. P.M., TUESDAY, FEBRUARY 14, 1882. 5 FEET ABOVE FLOOR.

TIME. H. M.	4 inches from outside. Deg. F.	16 inches from outside. Deg. F.	28 inches from outside. Deg. F.	TIME. H. M.	4 inches from outside. Deg F.	16 inches from outside. Deg. F.	28 inches from outside. Deg. F.
8 15 A.M.	118	267	283	12 30 P.M.	150	319	355
30	140	285	297	45	150	319	362
45	140	292	316	1	150	317	389
9	141	290	331	15	150	350	418
15	142	294	328	30	164	353	430
30	141	299	341	45	166	349	466
45	141	296	352	2	175	359	466
10	141	296	352	15	182	380	471
15	142	320	348	30	182	374	476
30	142	308	362	45	180	308	479
45	142	306	359	3	180	300	481
11	142	302	365	15	181	309	488
15	142	298	370	30	180	302	495
30	142	292	376	45	180	310	498
45	142	296	382	4	180	303	503
12 M.	149	318	354	15	180	304	506
15 P.M.	150	313	369	30	180	293	509

the same distance vertically, and therefore only 10″ from it in a direct line.

The three profiles, Fig. 29, are separated by 12 inches of brick-work. They are noticeable for the sudden rise in the first 15 minutes, at 4″, and in the first 30 minutes, at 16″ and 28″; for the great depression, 12 M. to 1 P.M., at 28″, the still greater depression, 2:30 to 4:30, at 16″, caused by keeping fire-doors open to prevent blow-

ing off steam at the safety-valve; and in the 4″ hole by the two well marked level lines—8:30 to 11:45, and 2:15 to 4:30, with the intermediate steps. The dotted curves which indicate assumed means in this figure are rather violent assumptions, especially at 16″; but this, again, will be seen to be of no importance.

Fig. 30, showing hourly mean transverse temperatures, Fig. 31, showing hourly actual transverse temperatures, and Fig. 33, showing quarter-hourly actual transverse temperatures, being similar in construction to figures already described in connection with Table XXIX., require no comment.

Fig. 31.
HOURLY ACTUAL TEMPERATURES IN BRICK-WORK: FROM TABLE XXXII.
TUESDAY, FEBRUARY 14, 1882

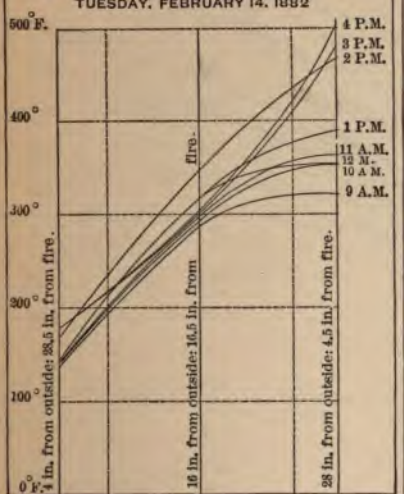
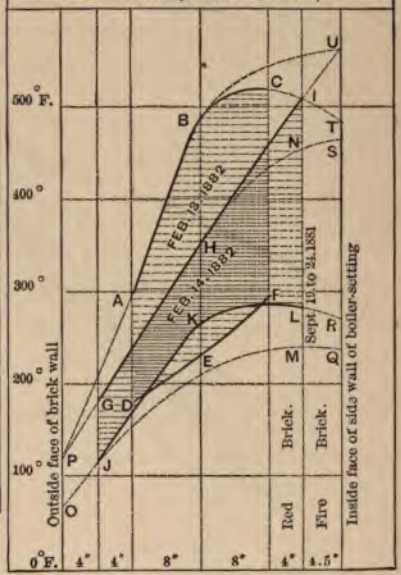


Fig. 32 GRAPHICAL REPRESENTATION OF EXTREME TEMPERATURES IN BRICK WORK: FROM TABLES XXX, XXXI, AND XXXII,



In Fig. 32, the extreme temperatures—highest and lowest—of all three tables, XXVIII., XXIX., and XXX., are grouped together in their appropriate positions in the brick-work. The full vertical line M N represents the entire range of the 241 quarter-hourly observations in the 28-inch hole, during the week Sept. 19–24, 1881.

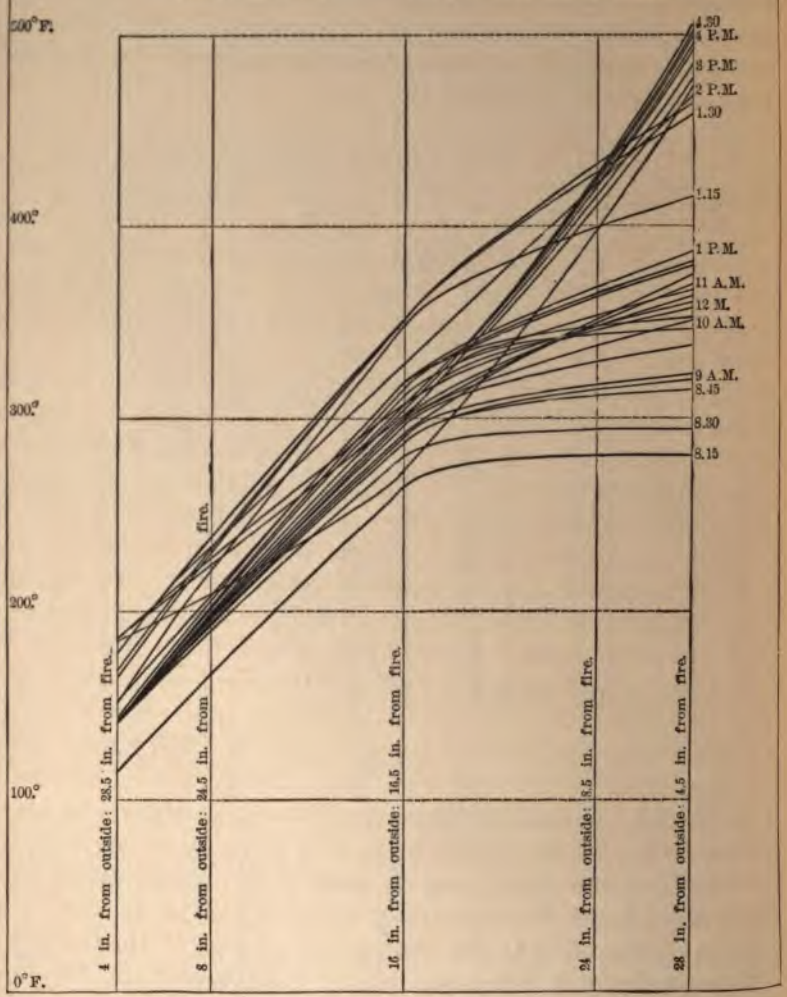
The curved line A B C represents the upper, and the line D E F the lower temperatures, observed on Monday, February 13, 1882; and the shaded space between these lines and the vertical dotted lines at 8″ and 24″ from the outside, represents the whole range of the 72 temperatures observed on that day.

The oblique, nearly straight line, G H I, represents the upper, and the sharply bent line J K L, the lower temperatures observed on

Fig. 33.

ACTUAL QUATER-HOURLY TEMPERATURE IN BRICK-WORK:

FROM TABLE XXXII TUESDAY, FEBRUARY 14, 1882.



Tuesday, February 14, 1882; and the shaded space bounded by these two lines and by the 4-inch and 28-inch verticals, represents the entire range of the 102 observed temperatures on that day.

The form of the curves of transmission, whether convex or concave upward, or straight, depends on the relation of the increment of heat at the inner surface, to the conductivity of the brick-work.

In Fig. 31, the hourly lines at 3 and 4 P.M., and Fig. 33, all the lines from 2 to 4:30, are concave upward, showing that heat was received at the inner face of the wall faster than it was conducted away. In Fig. 28, the 12 M. line is almost exactly straight, showing a balance of heat received and conducted; the lines below, especially those at 10 to 11:15, are concave upward, showing that heat is received at the inner face faster than it is conducted outward; and the upper lines, 2 to 4:15, are convex upward, showing that heat is conducted outward faster than it is received at the inner face.

Careful study of these diagrams will clearly teach the importance of thick walls around boiler furnaces. If the wall shown in section in Fig. 32 were, as is too commonly the case, only 16 or 16.5 inches in thickness, the temperature of the outer surface would never rise to 400° or 500° F., because the more active radiation would disperse the heat more rapidly; but this more active radiation would imply a higher temperature than here prevails at the outer surface, perhaps as high as is here found at a depth of 4 to 6 inches, say 120° to 200° F. The mass of brick masonry constituting the inner foot in thickness of a wall two feet or more in thickness, is no mean equalizer of temperatures in the furnace and combustion-chamber of an externally fired boiler. Taking into consideration only five feet in height and one foot in thickness on each side of the furnace, and 26 feet in length (including the cross-wall in rear), we have $2 \times 5 \times 26 = 260$ cubic feet, weighing 100 lbs. per cubic foot, of one-fifth the specific heat of water, equal therefore to 20 lbs. of water per cubic foot; and $260 \times 20 = 5200$. A range of temperature of 200°, from 250° to 450° F., will therefore imply an increase or diminution in the quantity of heat of say 1 000,000 British thermal units, equal to the evaporation from and at 212° F. of more than 1,000 pounds of water. Radiation from brick-work to boiler is rapid and constant, and tends sensibly to maintain uniformity in the transmission of heat to the boiler and its contained water, when the fire-doors are opened for firing, or for cleaning the grates, and when the grates are covered with freshly fired coal not yet fully ignited. The ideal boiler setting will contain, among other things, a series of three-eighths inch iron pipes, welded up at the lower end, inserted vertically, at various

distances from the outer surface of the walls, and to various depths, to contain mercury, for the more complete study of the subject under consideration by the patient and long continued use of the thermometer.

Power consumed in driving blower.—The Root blower was driven by a Hoadley portable steam engine detached from its boiler, made by Geo. T. McLauthlin & Co., Boston, 5.5 inches diam-

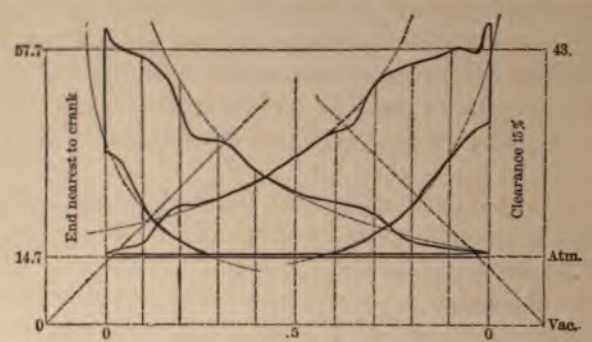


Fig. 34.

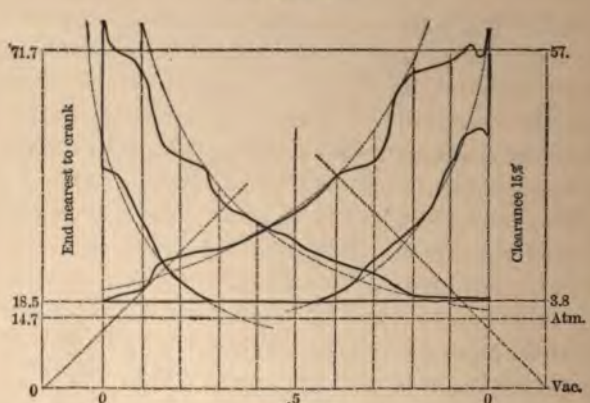


Fig. 35.

eter of cylinder, and 8 inches stroke, easily capable of producing 9 horse-power, indicated. Its automatic cut-off was adjustable between the limits of 125 and 325 revolutions per minute, by means of a change of links confining the ends of the governor springs.

Steam pressure varied rapidly and widely on account of the variable requirements of the chemical works for steam, so that without automatic cut-off no tolerable regularity of speed could have been maintained.

Indicator diagrams were taken from both ends of the cylinder under various conditions. Two pair of these are given exactly as they were taken, save that they are here reduced to half their original length, the scale of pressures unaltered. In both cases the speed was 200 revolutions per minute. In Fig. 34 the engine was exhausting into the air, and the back pressure was only about 15 pounds absolute. In Fig. 35 the engine was exhausting into an extemporized surface condenser with about 3.8 pounds per square inch back pressure, above the atmosphere, equal to 18.5 pounds absolute. Clearance, ascertained by filling the space with water, was equal to 15 per cent. of the volume swept through by the piston, allowance being made for the volume of the piston-rod at the end nearest to the crank.

There is evidence of leakage in the compression lines. The power shown in Fig. 34 is 2.96 horse-power indicated. The quantity of visible steam exhausted is equal to 40.86 pounds per horse-power per hour.

In Fig. 35 the power is 2.77 horse-power indicated, and the quantity of visible steam is 43.1 pounds per horse-power per hour. On the 23d day of September, 1881, a very careful experiment was made to ascertain the quantity of heat rejected by the engine while driving the blower, by condensing all the steam from the exhaust pipe, and noting the quantity of water used for condensing and its initial and final temperature. For this purpose the steam calorimeter previously described was used.

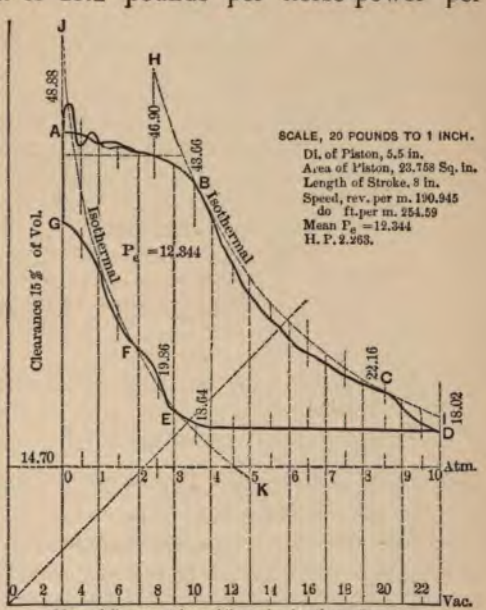


FIG. 36.

Water from a cask placed on a roof, maintained at a constant level by a "ball and cock," was led by pipes to the interior of the calorimeter and distributed by seven pipes of three-quarter inch gas pipe, one passing down

the center in the space usually occupied by the shaft of the agitator, and the other six spaced equally around the sides between the calorimeter lining and the steam drum. Water was supplied to these pipes equally by branches from a vertical, centrally located two-inch pipe extending from the cask.

The water so supplied proved to be adequate to condense the steam at only three to four pounds pressure above the atmosphere (Fig. 36). A weir was fitted to the top of the calorimeter to discharge this water through a spout into a cask placed conveniently near on scales. Delicate and accurate thermometers having their bulbs immersed in small vials filled with oil were placed in the inflowing and outflowing streams, and the temperature they indicated was noted once a minute. The oil in which the bulbs were immersed served to integrate the momentary variations of temperature due to imperfect mixing, so that the changes were moderate both in rapidity and extent.

Time of beginning the experiment, P. M.	4 h. 13 m. 58.5 s.
Time of ending the experiment, P. M.	5 h. 35 m. 9.0 s.
Duration of experiment	1 h. 21 m. 10.5 s.
= 1.3529166 h. = 81.175 m. = 4870.5 seconds.	
Reading of counter on engine, final	3122000
Reading of counter on engine, initial	3106500
Number of revolutions of engine in 81.175 minutes	15500
Mean number of revolutions of engine per minute	190.9455
Mean velocity of piston in feet per minute	254.59
Flow of water over weir, 413 lbs. in	5 m. 56.00 s.
Again, 413 lbs. in	5 m. 55.50 s.
Again, 413 lbs. in	5 m. 55.25 s.
Mean flow of water over weir, 413 lbs. in	5 m. 55.58 s.
Total quantity of water in 81.175 minutes, lbs.	5657.
Quantity of water per minute, lbs.	69.689
Quantity of water per hour, lbs.	4181.34
Quantity of water per horse-power per hour, 2.08 indicated horse-power, lbs	2010.26
Total quantity of exhaust steam and entrained and condensed water, lbs.	237.
Steam and entrained and condensed water per hour, during 1.3529 hours, lbs.	175.18
Steam and entrained and condensed water per horse-power per hour; 2.08 indicated horse-power, lbs.	84.22
Ratio of condensing water to steam	23.87
Mean final temperature of condensing water	109.9° F.
Mean initial temperature of condensing water	68.2° F.
Mean rise of temperature	41.7° F.
Number of B. t. u. added to each one pound of water = 110.0047 − 68.2683, B. t. u.	41.7364

Total number of B. t. u. added to 5657 lbs. of water in 81.175 m....	236102.8
Mean temperature of condensed steam.....	94.9° F.
Difference in quantity of heat between water at 94.9° F. and at 68.2° F. = 94.9648 − 63.2683 = B. t. u.....	26.6965
Quantity of heat carried off by water condensed from steam (237 lbs.) above initial temperature of condensing water = (94.9648 − 68.2683) × 237 = B. t. u.....	6327.1
Total quantity of heat rejected by the engine and found in the condenser, 236102.8 + 6327.1 = B. t. u....	242429.9
Power represented by the mean indicator, diagram, Fig. 195; mean of five diagrams taken from the end of the cylinder farthest from the crank; three others, substantially like these, being slightly imperfect, are rejected. I. h. p	2.268
Ratio of the mean power at the two ends of the cylinder to the power developed at the end farthest from crank, per cent.....	91.78
Power developed at both ends of the cyl., 2.686 × .9178 = i. h. p.....	2.08
British thermal units equal to 2.08 indicated h. p. during 81.175 minutes, $= \frac{2.08 \times 33000 \times 81.175}{772}$ = B. t. u.....	7217.42
Steam pressure, absolute, in condenser, lbs. per sq. in...	18
Heat, above 0° F. contained in one pound of steam of 18 lbs. pressure per sq. in absolute, B. t. u..... ...	1181.7640
Heat above 0° F. contained in one pound of water of temperature of condensed steam, 94.9° F., B. t. u.....	94.9648
Quantity of heat to be subtracted from one pound steam of 18 lbs. per sq. in. pressure absolute, to condense it to water of 94.9° temperature, B. t. u.....	1086.7992
Number of pounds of steam of 18 lbs. per sq. in. p. abs. condensed by convertion of heat into work in the engine, 2.08 i. h. p. during 81.175 minutes, $= \frac{7217.42}{1086.7992}$ = lbs.....	6.641
Per horse-power per hour, $\frac{6.64 \times 60}{2.08 \times 81.175}$ = lbs...	2.36
Number of pounds of visible steam, according to indicator cards, per horse-power per hour, lbs.....	41.77
Quantity of steam, visible, and condensed in doing work, per h. p. per hour, 2.36 × 41.77 = lbs.....	44.13
Quantity of entrained water, condensation in pipes and cylinder (not in doing work), and leakage; being the excess of total steam and water admitted to steam drum (237), over visible steam and steam condensed in doing work (124 lbs.), per i. h. p. per hour,	

$= \frac{237 \times 60}{81.175 \times 2.08} - 44.13$, = lbs..... 40.09

Ratio of excess to steam visible:

$\frac{40.09}{44.13} = .9084$, = per cent..... 90.84

Ratio of excess to total:

$\frac{40.09}{84.22} = .476$, = per cent..... 47.6

Ratio of visible steam, etc., to total:

$\frac{44.13}{84.22} = .524$, = per cent..... 52.4

Speed of blower corresponding to 191 rev. of engine per minute..... 2.32

Rate of combustion of anthracite corresponding to 232 rev. of blower per m. (232 × .07169), in pounds of coal per sq. ft. of grate area per hour (by experiment)..... 16.63

Pounds of coal burned per hour on fire-grate, 16.63 × 25.83 = lbs..... 430

Pounds of water evaporated from and at 212° F. per hour, 430 × 11.71 lbs..... 5035.

Ratio of all water passing through the engine to water evaporated,

$\frac{175.18}{5035} = .035$ = per cent..... 3.5

This engine, then, was using 3.5 per cent. of all the water evaporated; but at the rate of 84.22 pounds of water per horse-power per hour. If power were supplied from a large engine, of good construction, 24 pounds of water per horse-power per hour would be sufficient; and $\frac{24}{84.22} = .287$, and $.287 \times 3.5 = 1$.

Therefore, the steam required to drive the blower, with a reasonably good engine, running with 24 pounds of water per indicated horse-power per hour, is 1 per cent. of the steam generated by its use.

It may be worth noting that the circumference of the engine-pulley was 113.30 inches, and that of the blower pulley, 92.87 inches. The number of revolutions made by the engine and blower respectively, during weeks G, ending February 4, and H, ending February 11, 1882, and the running time each week, were:

	Running time. Minutes.	Whole number of revolutions of Engine.	Whole number of revolutions of Blower.
Week G.....	3272	542624	659808
Week H.....	3156	508176	616088
Total, 107 h. 8 m. =.....	6428	1050800	1275896

The ratio of these numbers is:

$$\frac{1275896}{1050800} = 1.2142$$

and $$\frac{113.3}{92.87} = 1.2200$$

Difference = "slip" = .0058—say about 0.6 per cent.

SOLID CARBON AND ASH IN FLUE GASES.—During the week ending August 20, 1881 (week F), the fuel being bituminous coal, an experiment was made by Mr. Prentiss to determine the quantity of solid matter—finely comminuted carbon and ash—borne off in the cloud of black smoke which to vulgar apprehension appears to present a formidable loss of combustible material, and is in fact a palpable and serious nuisance.

A stream of gas directly from the flue was drawn by an aspirator through a gas meter, to measure its volume; and as its pressure and temperature were observed, and as the error of the gas meter was ascertained, the weight of the gases became known. The stream of gas—smoke—was made to pass through a strainer of muslin, in the form of a bag, secured at the bottom of a vessel of water, which retained, mechanically, some of the soot, and caused the rest to be diffused and retained in the water, while the gas bubbled up and escaped from the water perfectly clear. When a sufficient and known quantity of the gases had been so passed, the water was evaporated, and the residuum was dried and weighed.

One hundred cubic feet by the meter, equal to 108.53 cubic feet corrected, at 72° F., weighing 534 grains = 0.0762857 lb. per cubic foot, yielded 0 49 gramme = 7.57 grains = 0.001081 lb. of solid matter; and 1 cubic foot, therefore, yielded 0.00001 lb.

The quantity of coal burned during the week, was 12890 lbs.; the mean quantity of flue gas per lb. of coal was 25.23 lbs.; and the total quantity of flue gas was 25.23 × 12890 = 325215 lbs.

The volume of this gas, at 72° F., was

$$325215 \div 0.0762857 = 4263119 \text{ cubic feet,}$$

yielding 4263119 × .00001 = 42.63 lbs. of solid matter—soot. The ratio of this soot to the total quantity of coal burned is,

$$\frac{42.63}{12890} = .0033 = 0.33 \text{ per cent.}$$

No analysis was made of this solid matter, as there seemed to be

[illegible]

It may be worth noting that the circumference of [illegible] was [illegible] inches, and that of the blower [illegible] inches. The number of revolutions made by the [illegible] were respectively, during weeks G, ending Februa[ry illegible] ending February 11, 1882, and the running time each [illegible]

	Running time. Minutes.	Whole number of [revolutions] of Engine.
Week G	3272	542624
Week H	3156	508176
Total, 107 h. 8 m. =......	6428	1050800

he ratio of these ...

$$\frac{127.8}{...} = 1.1142$$

nd $\frac{113.3}{92.57} =$ 1.2200

ifference = "slip" = .0058—say ... per cent.

OLID CARBON AND ASH IN FLUE GASES.— During the week ... gust 20, 1881 (week F), the fuel being bituminous coal, an ... ment was made by Mr. Prentiss to determine the quantity of d matter—finely comminuted carbon and ash ... d of black smoke which to vulgar apprehension appears to ... a formidable loss of combustible material, and is ... le and serious nuisance.

stream of gas directly from the flue was drawn ... through a gas meter, to measure its volume; and ... temperature were observed, and as the error ... ascertained the weight of the gases ...

[illegible]

no way of completely separating it from the muslin bag, and the quantity was extremely small.

Its gray color indicated that not more than one-half was carbon. The proportion of carbon carried off in the black smoke of this bituminous coal, would, therefore, appear to be not far from one-sixth of one per cent.

APPENDIX A.

MEMORANDUM of agreement by and between Obadiah Marland of Boston, in the County of Suffolk and Commonwealth of Massachusetts, and
the Pacific Mills, of Lawrence, Massachusetts,
the Massachusetts Cotton Mills, of Lowell, Massachusetts,
the Boott Cotton Mills, of Lowell, Massachusetts,
the Naumkeag Steam Cotton Company, of Salem, Massachusetts,
the Atlantic Cotton Mills, of Lawrence, Massachusetts,
the Great Falls Manufacturing Company, of Great Falls, N. H.,
the Boston Manufacturing Company, of Waltham, Massachusetts,
the Merrimack Manufacturing Company, of Lowell, Massachusetts,
the Salmon Falls Manufacturing Company, of Salmon Falls, N. H.,
the Nashua Manufacturing Company, of Nashua, New Hampshire.
the Lancaster Mills, of Clinton, Massachusetts,
the Manchester Mills, of Manchester, New Hampshire,
S. D. Warren & Co., of Cumberland Mills, Cumberland, Maine.

The said corporations and manufacturers agree to make and cause to be made a test of the apparatus set forth and described in United States Letters Patent, No. 205,282, to O. Marland, dated June 25, 1878, and Great Britain Letters Patent, No. 2553, to said Marland, dated June 26, 1878, in accordance with the description of said apparatus contained in said Letters Patent, at the Pacific Mills in the City of Lawrence, Massachusetts, under the supervision, control and direction of John C. Hoadley, at their joint expense and cost, in the manner and upon the conditions named herein.

Said test to be made forthwith and without delay as soon as the said apparatus can be properly constructed and placed in operation at said Pacific Mills.

Said test to be made with reference to the combustion of both

anthracite and bituminous coals, and the device for superheating air as set forth in said Letters Patent or either thereof shall be applied to the furnace or furnaces used to make said test.

The expense and cost of said test and the apparatus constructed therefor shall be borne and paid by said corporations and manufacturers respectively according to the number of boilers now in use at their mills named herein set against their names hereto respectively.

Said test to be made and a full and complete report thereof to be made by the engineers and experts employed by said corporations and manufacturers to make said test and to be furnished in writing signed by said engineers and experts to said corporations and manufacturers as soon after said test is completed as said report can be prepared, and a copy of said report to be furnished to said Marland.

When said John C. Hoadley shall give notice in writing to said corporations and manufacturers and said Marland that said test has been made, then it shall by the parties to this memorandum be deemed to be made.

All upon the condition that not less than two hundred (200) boilers shall be represented by the corporations and manufacturers named herein.

And the said Obadiah Marland, for himself, his executors, administrators and assigns, agrees to issue and grant unto each and every of the corporations and manufacturers herein named whose signatures are placed hereto, absolute license for the full term of said Letters Patent and all reissues and extensions thereof, without charge for royalty, rental or otherwise, to apply and use his invention set forth in said Letters Patent upon and in connection with any and all boilers for stationary purposes which now are in use or which may be constructed to be used in the mills now owned by said corporations and manufacturers at the places named herein and set against their names hereto respectively.

Said right and license by said Marland or his executors, administrators or assigns, to be made by him or them to said corporations and manufacturers in due form in writing as soon as said test shall be made and the report thereon in writing made by said engineers and experts and furnished to said Marland or his executors, administrators or assigns.

In consideration of the mutual promises of the parties hereto, the said Marland and the said corporations and manufacturers have sev-

erally placed their hands and affixed their seals hereto, this twelfth day of February, A.D. 1881.

Signed,

	Obadiah Marland,	[L. S.]
NO. OF BOILERS.		
50	Pacific Mills, Lawrence, by Henry Saltonstall, Treas.,	[L. S.]
12	Boston Mfg. Co., Waltham, by Edmund Dwight, Treas.,	[L. S.]
9	Naumkeag Steam Cotton Co., Salem, by H. D. Sullivan, Treas.,	[L. S.]
10	Atlantic Cotton Mills, Lawrence, by Wm. Gray, jr., Treas.,	[L. S.]
18	Massachusetts Cotton Mills, Lowell, by Geo. Atkinson, Treas.,	[L. S.]
13	Great Falls Mfg. Co., Great Falls, by A. P. Rockwell, Treas.,	[L. S.]
37	Manchester Mills, Manchester, by John C. Palfrey, Treas.,	[L. S.]
10	S. D. Warren & Co, Cumberland Mills,	[L. S.]
9	Merrimack Mfg. Co., Lowell, by C. H. Dalton, Treas.,	[L. S.]
13	Boott Cotton Mills, Lowell, by Augustus Lowell, Treas.,	[L. S.]
3	Salmon Falls Mfg. Co., by H. Stockton, Treas.,	[L. S.]
8	Nashua Mfg. Co., by Frederic Amory, Treas.,	[L. S.]
10	Lancaster Mills, Clinton, by James S. Amory, Treas.,	[L. S.]

APPENDIX B.

COMBUSTION OF FUEL.

BY J. C. HOADLEY.

THE perfect combustion of one pound of pure carbon produces, it is said, heat equal to 14,500 thermal units; *i. e.*, heat enough to raise the temperature of 14,500 pounds of ice-cold water 1° Fahrenheit. No coal, no coke, consists of pure carbon. Commercial anthracites yield, on analysis, about five per cent. of oxygen and hydrogen united in the form of water, so that the hydrogen is of no calorific value. There is also a varying proportion of earthy matter left in the furnace after combustion—in part also drawn into the flues and chimney—ranging from 5 to 15 per cent. The purer coals are apt to crumble so badly in heating, for want of the tenacity which a larger proportion of "ash" would give, that they often suffer considerable loss by decrepitation, and sifting through the fire into the ash-pit unburned. These causes reduce the theoretical value of one pound of commercial coal (anthracite) about one-sixth, or from 14,500 to 12,083 thermal units.

Each thermal unit is equal to 772 foot-pounds of work, so that the perfect combustion of one pound of commercial anthracite coal is equal to

$$12{,}083 \times 772 = 9{,}328{,}076 \text{ foot-pounds.}$$

One horse-power exerted during one hour is $33{,}000 \times 60 = 1{,}980{,}$

000 foot-pounds; therefore, if all the work represented by the perfect combustion of the carbon contained in one pound of commercial coal in one hour could be converted into useful work in an engine, it should produce

$$\frac{9328076}{1980000} = 4.711 \text{ horse-power one hour;}$$

and each horse-power should require, each hour,

$$\frac{1980000}{9328076} = 0.212 \text{ pounds of coal.}$$

But in fact, instead of about one-fifth of one pound, the very best engines require ten times as much, or two pounds per hour. Very good practice requires fifteen times as much, or 3.0 to 3.25 pounds; and the great majority of good engines consume from fifteen to twenty times the above quantity—that is, 3.25 to 4.25 pounds of coal per horse-power per hour—and show a ratio of actual performance to the full calorific power of the fuel consumed of 5 to 6 per cent. But this loss of from nine-tenths to nineteen-twentieths of the work represented by the combustion of coal—almost startling when contemplated for the first time—is in great measure irremediable in the steam engine, arising as it does from the physical properties of water, employed as a vehicle for the use of heat. The problem in the steam engine is to convert the molecular motion of heat into the sensible motion of ponderable masses—a piston, fly-wheel, etc.; and the degree in which it is possible for it to accomplish this, every imperfection and every source of loss eliminated, is the ratio which the difference of temperature of initial and exhaust steam (or its "range") bears to the absolute temperature of initial steam; that is, $\frac{T_0 - T_1}{T_0}$, where T_0 is the absolute initial temperature, and T_1 the absolute final temperature. For instance, if in a locomotive steam be taken into the cylinder up to the point of cut-off, at 120 pounds per square inch, steam-gauge pressure (above a mean atmospheric pressure of 14.7 pounds) = 134.7 pounds absolute pressure, its sensible temperature Fahrenheit will be 350°, and its absolute temperature 461° greater, or 350 + 461 = 811°. Exhausted under pressure a little greater than that of the atmosphere, say 15 pounds per square inch absolute pressure, its sensible heat Fahrenheit will be 213°, and its absolute temperature will be 461° more, = 213 + 461 = 674°. Now, if $T_0 = 811°$, and $T_1 = 674°$, then $\frac{T_0 - T}{T_0} = \frac{811 - 674}{811} = \frac{137}{811} = 0.169$, or say $16\frac{9}{10}$ per cent. That is, the range of temperature between initial and

exhaust steam being 137° Fahrenheit, and the absolute initial temperature being 811° Fahrenheit, such a steam engine, on account of being obliged to let the steam go while it still has a temperature 213° above zero Fahrenheit = 674° above absolute zero (which is 461.2° say, 461° below zero Fahrenheit), has within its reach, if it could save it all, only 16.9 per cent. of the whole work contained in the initial steam in the form of heat. Such an engine will in fact yield about 6 per cent.; and, dividing this 6 per cent. by the 16.9 per cent., we have $\frac{6}{16.9} = .355$, or 35.5 per cent., as the ratio of usual engine performance to *perfect* performance of a perfect heat engine, under the above usual conditions.

About two-thirds, then, of the heat work that may at least be striven for is usually lost.

Where is this loss? In the engine chiefly; but the boiler must come in for a share.

Let us see what the boiler's share of this loss amounts to. Pure carbon perfectly burned, with just sufficient air to supply the requisite oxygen, will produce mixed gases weighing 12.6 pounds for each pound of carbon:

Carbon,	1.0	Carbon,	1.00	
Air,	11.6	Oxygen,	2.66	
	12.6	CO_2	3.66	}
		Nitrogen,	8.94	} Products.
			12.60	}

The specific heat of carbon dioxide is 0.216; that of oxygen, 0.217; nitrogen, 0.244; atmospheric air, 0.238. It follows that the specific heat of all the products of combustion, with whatever excess of air over that chemically necessary to the complete combustion of carbon, is about 0.237, and that, to heat one pound of water 1° Fahrenheit, 4.22 pounds of such gaseous products must be cooled an equal amount. If a pound of coal were pure carbon, its gases would weigh, without excess of air, 12.6 pounds; with 50 per cent. surplus, 18.4 pounds; with 100 per cent. surplus, 24.2 pounds; with 125 per cent. surplus, 27.10 pounds; and with 150 per cent. surplus, 30.00 pounds. But of commercial coal only five-sixths is carbon. We neglect the water (or oxygen and hydrogen) —as the quantity, small at most, is variable, and its effect on the result would not justify the complication its consideration would cause—and simply take five-sixths of the above quantities, and tabulate them, with the corresponding weight of water per degree, *and the* thermal units expressed in foot-pounds.

TABLE I.

GASEOUS PRODUCTS OF THE COMBUSTION OF ANTHRACITE COAL, AND THE LOSS CAUSED BY THE ESCAPE OF THESE GASES AT SEVERAL ASSUMED TEMPERATURES; WITH JUST SUFFICIENT AIR FOR PERFECT COMBUSTION, AND WITH VARIOUS DEGREES OF SURPLUS, 50, 100, 125, AND 150 PER CENT.

Excess of air above that chemically necessary for combustion of carbon, per cent. of the necessary quantity.	Weight of the gaseous products of combustion of the carbon in one pound of anthracite coal, 5-6 of coal.	Corresponding weight of water which could be heated 1° by cooling these gases 1°.	Thermal units expressed in foot-pounds, one thermal unit being 772 foot-pounds.	Total for 300° above external air. Foot-pounds.	Total for 400° above external air. Foot-pounds.	Total for 500° above external air. Foot-pounds.
1	2	3	4	5	6	7
	Pounds.	Thermal units.	Foot-Lbs.	Foot-Lbs.	Foot-Lbs.	Foot-Lbs.
0	10.50	2.4881	1,921	576,300	768,400	960,500
50%	15.333	3.6335	2,805	841,500	1,122,000	1,402,500
100%	20.166	4.7788	3,689	1,106,700	1,475,600	1,844,500
125%	22.583	5.3515	4,131	1,239,300	1,652,400	2,065,500
150%	25.000	5.9242	4,573	1,371,900	1,829,200	2,286,500

I have made the divisions above mentioned for various temperatures, ranging from 300° to 700° above the external air, and have tabulated the result in the following table:

TABLE II.

RATIO, PER CENT., OF THE HEAT CARRIED OFF BY THE GASEOUS PRODUCTS OF COMBUSTION TO THE TOTAL CALORIFIC POWER OF EACH POUND OF COAL; WITH VARIOUS DEGREES OF EXCESS OF AIR, AND AT VARIOUS TEMPERATURES OF THE ESCAPING GASES ABOVE THE EXTERNAL AIR.

Excess of air above that chemically necessary for combustion of carbon, per cent. of the necessary quantity.	RATIO OF LOSS TO TOTAL CALORIFIC POWER. PER CENTUM. Temperatures above external air.						
	300°	400°	5 0°	600°	700°	800°	75°
1	2	3	4	5	6	7	8
0	6.18	8.24	10.30	12.36	14.42	16.47	1.55
50%	9.02	12.03	15.04	18.04	21.05	24.06	2.25
100%	11.86	15.81	19.77	23.72	27.67	31.63	2.97
125%	13.29	17.72	22.15	26.58	31.01	35.44	3.32
150%	14.71	19.61	24.52	29.42	34.32	39.23	3.68

Since, as we have seen, the total calorific power of the five-sixths of a pound of carbon in one pound of commercial coal is five-sixths of 14,500, equal to 12,083 thermal units of 772 foot-pounds each, equal to 9,328,076 foot-pounds, the numbers in the columns 5, 6, and 7 of Table I., divided by 9,328,076, will give the respective ratios of loss from this cause in each case.

Doubts may be entertained as to so large an excess of air as 150 per cent. occurring in practice. In fact, it is very common. It is not easy to carry on complete combustion by means of natural draft with less than 100 per cent. excess—*i. e.*, double the necessary quantity—reckoned as it usually is at 12 pounds of gases absolutely necessary per pound of *coal*, as if coal were entirely composed of carbon. Now, 25 pounds of gaseous products for the combustion of one pound of anthracite coal containing only five-sixths of a pound of carbon, and producing, with no excess of air, only 10.5 pounds of gases, is equal to $(\frac{25}{10.5} = 2.38)$ 138 per cent. surplus air. Experiments to ascertain the composition, volume, and temperature of the gases from 17 boilers, burning good anthracite coal at a known rate, with great care, and under most favorable conditions of draft, grate area, rate of combustion, area of heating surface, and general management, gave, by analysis, carbon dioxide (no monoxide), nitrogen, and free atmospheric air—the latter being one-half of the whole. A check upon the accuracy of these results was found in the temperature of the furnace. This should be, with double supply of air, about 2,600° Fahrenheit. It was found to be a little less, about 2,400°. In my opinion, it is understating rather than overstating the matter to say that the average of good practice would show a double supply of air.

If we take as the most common boiler pressure in stationary boilers 80 pounds per square inch above the atmosphere—say 95 pounds absolute—its temperature, 324° Fahrenheit, will be that of the *cooling* surface to which the hot gases are exposed. In strictness, the temperature of the outside of the boiler plates will be higher than this, as 324° must be about their temperature inside, and the transmission of heat from without implies a higher temperature on the outer surface. Data exist for the computation of this exterior temperature under given conditions; but the computation is unnecessary here. It is probable that there can be no active transmission of heat from the gases without to the water within a boiler, with less than 75° difference of temperature within and without, which will include the difference in the two sides of

the plates. Professor Dwelshauvers-Dery, in an article published in the *Revue Industrielle des Mines*, of which a translation appears in Van Nostrand's *Engineering Magazine* for February, 1880, estimates this difference at 91° C. = 164° Fahrenheit, which seems to me excessive; but 75° is probably quite within the mark. Observation of a pyrometer in the smoke-box of a return-tubular boiler at all stages of the fire has satisfied me that in excellent boilers, well fired, having a ratio of heating surface to grate area as large as 36, the temperature of the escaping gases rarely, if ever, falls lower than 75° above the temperature due to the steam pressure, except when the fire-doors are open, and there is great and unusual excess of air admitted. Adding 75° to the temperature corresponding to 80 pounds steam-gauge pressure, 324°, we have, say, 400° as the lowest practicable temperature of escaping gases. This will be confirmed by the best practice under favorable conditions; and the actual temperature will range through a low average of 500° and a high average of 600° up to 800° or over; in some extreme cases going up to high incandescence, or over 1,000°.

How much of this loss can be saved and returned to the fire? By the Marland plan of passing the gases after their escape from the boiler through thin passages, the thin walls of which are in contact on their opposite sides with air for supplying combustion, entering with a current flowing in a direction opposite to that of the gases, the final temperature of the cooling surfaces becomes that of the external air, say, as an approximate mean, 60° Fahrenheit, to which the temperature of the gases may be made to approximate as closely as to the temperature of the water in the boiler, say within 75°, making their ultimate temperature, on release, 60 + 75 = 135°. This is not too hot for discharge through a Root blower, while it is too cool to give efficient draft in a chimney. At this temperature the ratio of irrevocable loss becomes one-fourth as much as at 300° above outside air, say, for double supply of air (100 per cent. surplus), 2.97 per cent.

I have set the several ratios in an additional column at the right hand of Table II., column 8. Taking now the ratios of loss, with 100 per cent. surplus air, from Table II., and subtracting from each one this final loss, we have

TABLE III.

RATIO, PER CENT., OF SAVING TO BE EFFECTED BY O. MARLAND'S SMOKE-COOLING AIR-HEATER, AT 100% SURPLUS AIR SUPPLY.

	TEMPERATURES OF GASES ON ESCAPING FROM BOILER ABOVE EXTERNAL AIR.					
	300°	400°	500°	600°	700°	800°
1	2	3	4	5	6	7
First loss	11.86	15.81	19.77	23.72	27.67	31.63
Final loss	2.97	2.97	2.97	2.97	2.97	2.97
Actual saving	8.89	12.84	16.80	20.75	24.70	28.66

It appears, then, that under ordinary circumstances from 16 to 20 per cent. of the total quantity of heat produced by the combustion of anthracite coal can certainly be saved and returned to the furnace by the Marland apparatus, judiciously arranged and proportioned; that in no circumstances can such saving fall so low as 10 per cent.; and that it will often be 25 per cent., and may, in extreme cases, reach 30 per cent.

The rate of evaporation per pound of coal from feed water at 60°, under 80 pounds steam-gauge pressure, say 324°, is certainly, in general, below 8 pounds. Indeed, 8 pounds of dry steam is a fair result, 8.25 pounds a good result, 8.5 pounds very good, and 9.0 pounds about the best usually attainable, being rather over 10,000 thermal units, which corresponds to 69 per cent. of the full calorific power of carbon, and is, for coal of five-sixths carbon, a high result.

If we take, as we properly may, 8.5 pounds of water evaporated into dry steam of 80 pounds steam-gauge pressure from feed water of 60°, with one pound of anthracite coal of five-sixths carbon, as corresponding to an air supply of 100 per cent. surplus, and escaping temperature of gases of 400° above external air, the apparatus, in effecting a saving of 12.84 per cent., would add to the evaporation, say, 12.84 per cent. of 10.8 = 1.4 pounds, making (8.5 + 1.4) 9.9 pounds; 10.8 pounds being the *full* evaporating power of such coal under the given conditions. To about this degree of efficiency, or to nearly or quite 10 pounds of water per pound of five-sixths coal from water of 60° to steam of 324° (80 pounds steam-gauge), this apparatus should be able to bring all good boilers, with whatever excess

12,083 Thermal Units

of air, or at whatever (reasonable) degree of heat, the gases were allowed to escape from the boiler. Not only will this apparatus restore to the furnace a large part—from four-fifths to eight-ninths of the heat otherwise inevitably lost; not only will it serve as a "heat-trap" to arrest and restore the loss otherwise inevitable by admission of cold air at the doors while firing and clearing out fires, and by the neglect or unskillfulness of firemen—it will also, I have no doubt, increase the rapidity of combustion, and so enable complete combustion to be carried on with a smaller quantity of air, *i. e.*, with less excess over the quantity chemically necessary.

It is true that by heating air from 60° up to 385° (that is, up to 400° above the temperature of external air less 75° of final difference), or from 521° to 846° absolute temperature, its volume will be increased in the ratio of these latter numbers, as 1 to 1.624, or about one to one and five-eighths: eight (8) cubic feet of air in the atmosphere will occupy thirteen (13) cubic feet in the pipes conducting it to the fire, whether above or below the grates.

Of course its density is in the same inverse ratio. Thirteen cubic feet of the heated air (385°) must be admitted to the fire and to contact with glowing fuel, in order to introduce as much oxygen as would be contained in eight cubic feet of the cold air (60°).

Equally, of course, the entering velocity must be greater in the some proportion, since the aggregate area of all the orifices through the grates and fuel may be regarded as constant.

This has been urged, sometimes most strenuously, as an objection to heating air before its introduction to the fire. The objection seems to me to rest on a partial view of the conditions of air-admission. It may be conceded that cold air in necessary quantity will enter the ash-pit, and will pass through the interstices of the grates, with less velocity than will the same quantity of heated air. But in these passages the area is (or always may be) amply large, and the velocity moderate. It is also true that, on entering the lower stratum of fuel, the velocity of the heated air will be the greater. But the very first effect of the chemical union of any part of the oxygen with any part of the carbon is to heat the gases associated with such oxygen—that is, its associated nitrogen and the atmospheric air yet containing its oxygen, together with the carbon dioxide resulting from such union or combustion—to the full extent to which the entire heat of combustion can raise the given mass of gases. This will be, approximately, the temperature of the furnace, a little modified, probably a little increased, by the

subsequent union of further portions of oxygen with new portions of carbon encountered during the farther progress of the mixed gases through the fuel, until they emerge, further de-oxygenated and further loaded with carbon dioxide, at the surface of the fire. If there is not, as there need not be, any carbon monoxide, the gases will be at their hottest and at their greatest volume on emerging from the surface of the fire.

Any further admission of air will only cool them by dilution. If their temperature be now 2,500° Fahrenheit = 2,961° absolute, their volume will be $\frac{2961}{521} = 5.7$ times that of air of temperature 60°, and $\frac{2961}{846} = 3.5$ times that of air of temperature 385°.

Now it is the volume of the gases at their final emergence from the interstices of the fuel that determines their flow—determines the force of draft or blower required to produce that flow. The expansion, which of necessity takes place in the most confined space—namely, in the interstices of the fuel—acts equally in all directions. Although all in motion upward through the fire, its upward portion, being most expanded, is moving more rapidly than its less expanded lower portion; and its expansive force, acting downwardly, simply retards the upward flow of entering air. Lateral expansion aids in bringing fresh oxygen into contact with unconsumed carbon. Upward expansion aids, and downward expansion retards, the draft. Now it is plain that this effect must be the greater, the greater the degree of expansion which takes place within the interstices of the fuel.

With air supply at 60°, it is 5.7-fold. With equal air supply (by weight), at 385°, it is 3.5-fold.

This difference is in the right direction to compensate, as far as it goes, for the greater force required to introduce the heated air with its greater volume and higher velocity, and certainly does compensate for it to some extent. My impression is, that it exactly balances the initial resistance; that the diminution of resistance to final expansion is an exact equivalent for the resistance encountered on entering; but this opinion is based on general dynamic considerations, and is not the result of special investigation. Certainly it cannot be far wrong.

Of the higher resulting temperature of the gases, there can be no question.

Nor can it be questioned that combustion will be more rapid.

Carbon (a solid) and oxygen (a gas) unite at all temperatures usually met. Anthracite coal wastes, in the open air, by slow combustion—so slow that the resulting heat, which is exactly the same as if the combustion were more rapid, is dissipated by radiation and the convection of the air. The rapidity of combustion is augmented with the rise of temperature, and is very great at high incandescence. Now, the temperature of the oxygen is no less important than that of the carbon: the higher the sum of their temperatures, the more rapid their union. So far as the associated gases are concerned, their higher temperature only serves to communicate more heat to the mass, or (which comes to the same thing) to abstract less from it.

Combustion being more rapid—being carried on with greater avidity—it seems certain that a smaller excess of air will be practically required; and, although the Marland apparatus diminishes the final loss from excessive air supply, it does not entirely remove it, since it must release the gases about 75° above the temperature of surrounding air. It also costs something to pass air through a blower or a chimney; and the less of it necessary, the better.

Grates of ordinary form could not endure a temperature of 400° or 500° in the ash-pit; but water grates are well known, and entirely available.

This device of Mr. Marland is an application of the well-known and firmly established principles of the Siemens regenerating furnace, by means of appropriate apparatus, to the conditions of such furnaces as those of steam boilers, and, if judiciously applied and worked out, should be as successful in its sphere as the Siemens furnace is in metallurgy.

This apparatus is particularly well adapted to the combustion of anthracite coal. Prideaux justly says (*The Economy of Fuel*, edited by D. K. Clark, New York, D. Van Nostrand, 1879, Part II., p. 211), "The less the quantity of hydrogen present, as with anthracite, the greater will be the chance of being able to seize the economic advantages attendant upon the increased quantity of heat attainable by the use of hot air, without having this heat so diluted as to make the temperature inefficient."

There can be no doubt that the heat to be returned to the furnace would several times exceed that necessary to make the power required to drive the exhausting fan, to the operation of which the final temperature of the gases presents no objection. No damage would probably be done to the plates of the air passages of this

apparatus by the heat of the entering gases in any admissible circumstances. Such gases are usually received from the flues of return-flue or return-tubular boilers, in plate-iron smoke-boxes, which prove as durable as other parts of the boiler and its appurtenances.

The passages are so divided that each one is thin, and the exposed surface is large, so that the temperature would fall rapidly, and thin plates must prove durable. The use of an exhaust fan will produce an inward draft at all orifices or leaks, which will merely increase, in some small but probably insensible degree, the load on the blower, but will, on the other hand, keep the incoming air free from carbon dioxide and nitrogen, and the fire-room free from noxious gases.

In the construction of new works the outlay for the Marland apparatus will be, or at least *may* be, largely offset by saving in the cost of a chimney.

If this apparatus can be successfully applied to marine engines, the gain by reduction of coal cargo, and by the increase of paying-freight carrying-capacity, is too obvious to require comment.

The arrangements for cleaning out the smoke passages seem to be convenient and efficient. The whole apparatus bears marks of thoughtful study, and seems to me to promise results worth some effort and expense to put to the proof of practical working.

APPENDIX C.

When these experiments were undertaken, it was assumed that certain letters patent granted to Obadiah Marland, described in Appendix A, might be considered valid. Subsequent investigation disclosed letters patent of Great Britain of earlier date, which seemed to limit, at least in some degree, the scope of the claims in said Marland's patents. Without expressing any opinion upon the effect of such apparent anticipation, I have thought it proper to call the apparatus used in these experiments (which differed in many respects from Marland's), by the general name of a "Warm-Blast Apparatus."

J. C. H.

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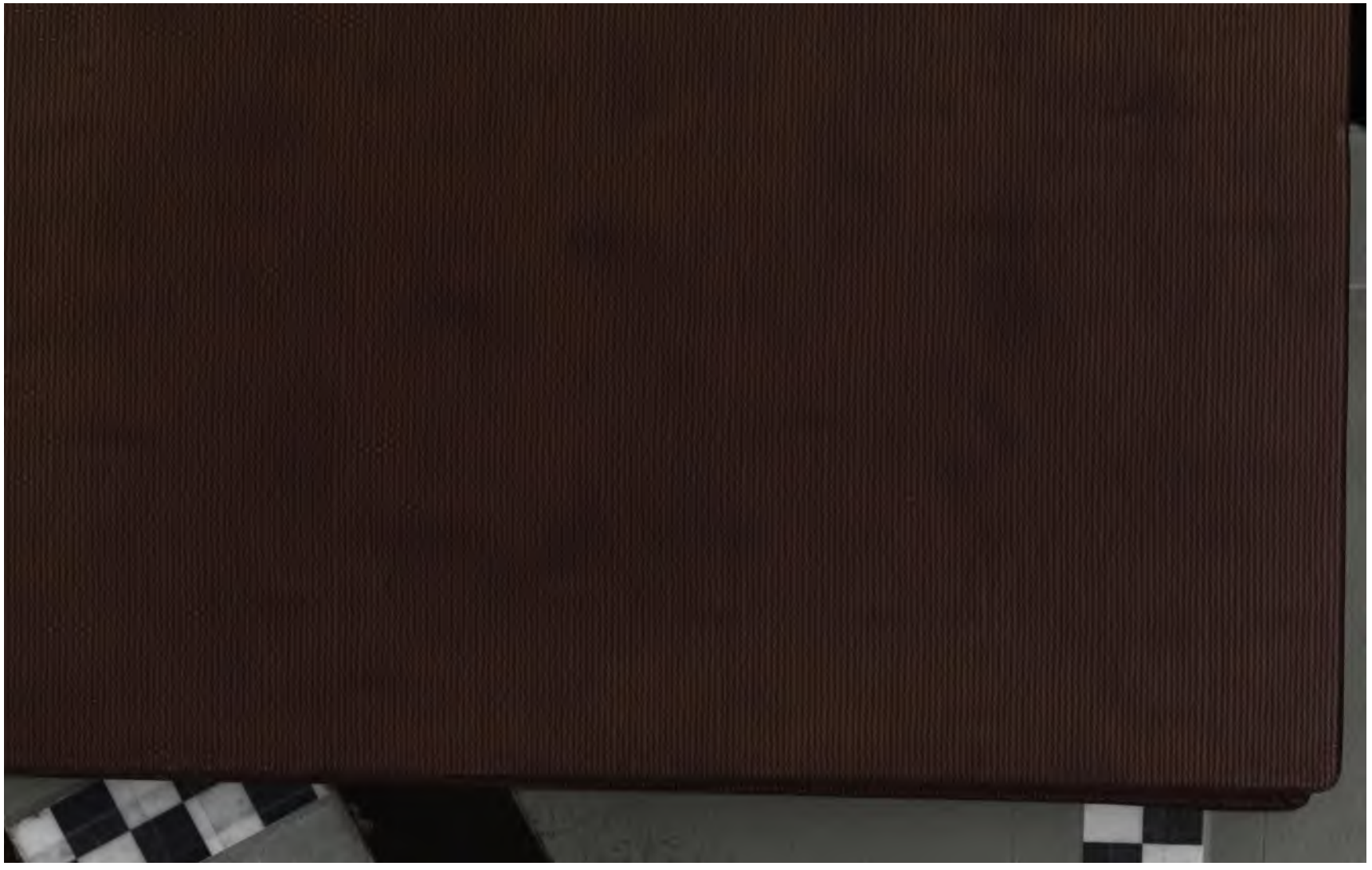
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